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# MINUTES OF PROCEEDINGS

OF

# THE INSTITUTION

OF

# CIVIL ENGINEERS;

WITH OTHER

## SELECTED AND ABSTRACTED PAPERS.

## VOL. CXXXVIII.

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J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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## CORRIGENDA.

Vol. cxxiv. p. 277, line 15, *for* "98 feet" *read* "28 feet."
„ cxxxiii. p. 286, line 12, *for* "Great Eastern" *read* "North Eastern."
„ „ p. 301, line 21, *for* "Mallett" *read* "Mallet."
„ „ Plate 4, Fig. 11, *for* "23·0" *read* "22·0."
„ cxxxvi. p. 365. The article by Alfred E. Wiener should be credited to the "American Machinist" of the 19th May, 1898, in which it originally appeared.
„ cxxxvii. p. 115, line 5 from bottom, *for* "Miners in England had never" *read* "The miners had never, as in England."
„ „ p. 124, line 2, *for* "Galwara" *read* "Gellivara."
„ „ p. 149, line 12 from bottom, *for* "18 inches" *read* "8 inches."

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THE

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SESSION 1898-99.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

28 March, 1899.

JOHN CLARKE HAWKSHAW, M.A., Member of Council, in the Chair.

*(Paper No. 3125.)*

# "Alloys of Iron and Nickel."

By ROBERT ABBOTT HADFIELD, M. Inst. C.E.

## INTRODUCTION.

THE effect upon iron of gradually increasing amounts of certain added foreign elements has already been investigated by the Author in experiments upon the mechanical and physical properties of alloys of manganese, silicon, aluminium, and chromium, both in the cast and forged conditions.[1] In the present Paper are given the results of a similar investigation of the alloys of iron and nickel. In a research of this nature it is important to avoid as far as possible the disturbing influences of a second foreign element, especially carbon. This is not easy, for, although in several classes of alloys it is not impossible to obtain alloys low in the chief disturbing element, carbon, the alloy must be sound and free from honeycombs, and it must be malleable when hot. In the series now described, the alloys were sound and free from blow-holes; they were well melted, of uniform composition, could be readily forged, and generally presented characteristics which enabled them to be submitted to the same comparative tests as the Author's previous series. The following Table gives the contents in carbon and nickel of the various specimens, from which it will be seen

[1] "Manganese in its Application to Metallurgy," Minutes of Proceedings Inst. C.E., vol. cxiii. p. 1; "Manganese Steel," Journal of the Iron and Steel Institute, 1888, p. 41; "Alloys of Iron and Silicon," *Ibid*, 1889, p. 222; "Aluminium Steel," *Ibid*, 1890, p. 161; "Alloys of Iron and Chromium," *Ibid*, 1892, p. 49.



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that the chief disturbing element, carbon, is low and varies but little. The other elements present were normal and probably not of much influence, at any rate in the unannealed and annealed conditions

| Mark of Specimen. | Analysis. | |
|---|---|---|
| | C. | Ni. |
| | Per Cent. | Per Cent. |
| A . . . . . | 0·19 | 0·27 |
| B . . . . . | 0·14 | 0·51 |
| C . . . . . | 0·13 | 0·95 |
| D . . . . . | 0·14 | 1·92 |
| E . . . . . | 0·19 | 3·82 |
| F . . . . . | 0·18 | 5·81 |
| G . . . . . | 0·17 | 7·65 |
| H . . . . . | 0·16 | 9·51 |
| I . . . . . | 0·18 | 11·39 |
| J . . . . . | 0·23 | 15·48 |
| K . . . . . | 0·19 | 19·64 |
| L . . . . . | 0·16 | 24·51 |
| M . . . . . | 0·14 | 29·07 |
| N . . . . . | 0·16 | 49·65 |

of the material prepared. A certain percentage of manganese was also necessary to ensure forgeability; its influence is considered later. The full analyses, including carbon, silicon, sulphur, phosphorus, manganese, and nickel, are given in Table I, Appendix III. A number of valuable results have been obtained by Mr. J. Riley,[1] but in many cases the variations in the carbon and other elements present were too great to enable definite conclusions to be drawn as to the actual properties of nickel-iron alloys alone; that is, as free as possible from carbon and other elements. The late Mr. J. F. Hall, of Sheffield, was also one of the earliest experimenters in England in this direction, and helped to draw special attention to this now valuable product, nickel steel.

## Part I.—Physical Data relating to Nickel and Iron.

*Nickel.*—Like iron, nickel possesses considerably different characteristics according to its condition, that is, whether in its cast or forged form. In the former, and like pure iron, it does not present any special use, but when forged its strength and other

[1] Journal of the Iron and Steel Institute, 1889, part I, p. 45.

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qualities are much improved. It is less white than silver, but more brilliant than platinum. Its density is to some extent determined by the method of its preparation.

The melting-point is placed by some observers at a higher, and by others at a lower, point than that of iron; it is probably about 1,500° C. The specific heat of nickel, a slightly carburized specimen obtained by the calcination of the oxalate in a closed vessel, was found by Regnault to be 0·1086; other specimens of purer character gave 0·1075 and 0·1108. The specific resistance of a bar, 1 centimetre in length and 1 centimetre square in section, was found by Matthiessen to be 12,600 C.G.S. units, and of wire, 1 metre in length and 1 millimetre square in section, 0·1604 ohm. Nickel, like cobalt, can be magnetized more easily than iron with feeble, but less easily with large magnetic forces. Its magnetic quality, as compared with iron, is as 1 is to 1·5; and the magnetic intensity disappears towards 400° (Becquerel). According to Deville, its tenacity, as compared with iron, is as 9 to 7; a wire of 2 millimetres diameter supporting without breaking a load of 320 kilograms.

It is stated that nickel has been detected in the sun's atmosphere, but it is not easy to state by whom it was first detected in this mundane sphere. As pointed out by Sir William Roberts-Austen,[1] Persian and Indian metal work show only small percentages of nickel, under 0·30 per cent., the metal, however, must for many centuries have been largely used in the East, as the late Dr. Walter Flight found coins of the King of Bactria with dates varying from 150 to 246 B.C., which contained nearly the same amount of nickel as modern nickel coinage. In other words, the present copper-nickel coinage of Germany and Belgium is of almost the same composition as that employed more than 2,000 years ago. The exact analysis of the Bactrian coins was—copper, 77·585 per cent., nickel, 20·038 per cent., cobalt, 0·544 per cent., and iron, 1·048 per cent. Sir William Roberts-Austen is of opinion that the present of coins, mentioned by Quintus Curtius, to Alexander from Oxydracæ and Malli, stated to be "white iron" (*ferrum candidum*), was probably composed of the white alloy of nickel and copper. Nickel was also used by the Chinese in their well-known alloy "Pacfong" (copper, 4 per cent., iron, 2 per cent., zinc, 25 per cent., nickel, 31 per cent.). When, therefore, the "discovery" of nickel in the 18th century is referred to, the knowledge and work of past ages is somewhat depreciated. The

[1] Cantor Lecture, Journal of the Society of Arts, vol. xli. p. 1028.



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knowledge of the ancients as to the production of this and other metals was probably of a much higher order than that for which they are now given credit.

The modern discovery of nickel, and that it was a new element, seems to have been made by the Swedish chemist, Cronstedt, probably in 1751; his early experiments and those of others are dealt with in Part III.

*Physical Data relating to Nickel.—Specific Gravity.*—The specific gravity or density of the metal is given in an interesting set of experiments by Mr. Moissan, and shown in the following Tables:—

SPECIFIC GRAVITY OF NICKEL OBTAINED BY REDUCTION OF THE OXIDE.

| | | |
|---|---|---|
| By carbonic oxide | 8·28 | (Richter.) |
| „ „ | 8·40 | (Tourte.) |
| „ „ and forged | 8·66 | (Richter.) |
| „ „ „ | 8·93 | (Tourte.) |
| By carbon | 9·0 | (Vauquelin and Hauy.) |
| „ | 8·90 | (Schroder.) |
| „ and forged | 8·82 | (Tupputi.) |
| „ and cast | 8·38 | ( „ ) |
| By hydrogen | 8·98 | (Rammelsberg.) |
| „ | 9·25 | ( „ ) |
| „ and cast | 8·57 | (Thompson.) |
| Nickel obtained by reduction of the oxalate | 8·63 | (Brunner.) |

The average is 8·3 for cast nickel, 8·8 for forged nickel, or finally 8·66.

*Atomic Weight, &c.*—The following Table gives further particulars of the physical qualities of the metal:—

| | | |
|---|---|---|
| Atomic weight | 58·6 | |
| A large number of very carefully carried out experiments by Professors W. Fresenius and H. Bayerlein (Zeitschrift für Analytische Chemie, November 3rd, 1894, p. 627) showed the atomic weight to be | 58·9033 | |
| At the same time the atomic weight of cobalt was taken and found to be | 59·7421 | |
| Atomic volume | 6·7 | |
| Specific heat | 0·10 | (Dalton.) |
| | 0·1035 | (Dulong.) |
| Coefficient of linear expansion | 0·000072 | (Roberts-Austen.) |

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| | | |
|---|---|---|
| Specific resistance of a bar 1 centimetre square by 1 centimetre long | 12,600[1] C.G.S. units. | (Matthiessen.) |
| Temperature coefficient | 0·62 | (Dewar and Fleming.) |
| Specific resistance of wire 1 millimetre square by 1 millimetre long | 0·1604 ohm. | |
| Melting point (as determined by Holborn and Wien) (Annalen der Physik und Chemie, vol. lvi., 1896, p. 360) | 1484° C.[2] | |
| Magnetic quality as compared with iron as unity | 1·5 | |
| Magnetic intensity disappears at about | 400° | (Becquerel.) |

*Hardness.*—No definite figures are obtainable regarding the hardness of nickel as compared with that of other metals. At the Berlin National Research Laboratory, approximate tests have been made, in which lead represented unity; the results are shown in the following Table:—

| | | | |
|---|---|---|---|
| Lead | 1 | Nickel | 3¼ |
| Tin | 1⅓ | Soft Steel | 4½ |
| Copper | 2¼ | Glass | 7⅔ |
| Zinc | 2½ | Hard Steel | 8½ |

But these values do not agree with the careful sclerometer work of Professor Turner, who found, with lead as unity, copper was 8, soft iron 15, and mild steel 21 times as hard. The Author has pointed out on page 9 that both forged and cast nickel are harder than soft iron, probably about 17 or 18 in the Turner scale, but cast and forged nickel differ considerably in their hardness, the latter being the softer.

In further experiments described by Professor Turner,[3] the relative value of nickel was found to be 1,410, with diamond

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[1] Dewar and Fleming obtained 12,323 C.G.S. units with 0·62 temperature coefficient, and for iron 9,065 C.G.S. units with 0·625 temperature coefficient.

Quite recently Dr. Fleming has measured the specific electrical resistance of a specimen of very pure electrolytic nickel prepared by Mr. J. W. Swan, F.R.S., and found that its value is 7,230 C.G.S. units at about 15° C. Contrasting this number with the value given by Matthiessen's tests, viz., 12,323 C.G.S. units at 0° C., it is clear that the electrical resistance of nickel may undergo great variations according to its mode of preparation.

Professor Barrett, F.R.S., has recently obtained a resistance of 10,500 C.G.S. units for specially pure Swedish charcoal iron furnished by the Author.

Dr. Fleming obtained for pure iron 9,060 C.G.S. units.

[2] At the same time the exact melting points were determined of palladium, 1,587° C., and platinum, 1,587° C. In comparison may be given Ag 971°, Au 1,072°, Cu 1,082° C.

[3] "The Hardness of Metals," Birmingham Philosophical Society, December 9th, 1886, Proceedings, vol. v. part ii.

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3,010, iron 1,375, cobalt 1,450, manganese 1,456, copper 1,360, aluminium 821, lead 570, potassium 230; but in face of the manganese determination, which is certainly not correct, as metallic manganese, judging from its properties in specimens containing 98 per cent. to 99 per cent. of the metal, is exceedingly hard, the above figures cannot be taken as more than approximate. This shows the extraordinary difficulty met with in accurately defining hardness, as no one has paid more attention to this subject than Professor Turner. The discrepancies now obtained are not the fault of the observer, but of the imperfect apparatus hitherto constructed, and the difficulty in defining what is meant by the term "hardness."

Owing to the influence of nickel upon the elastic limit of steel, it would be very useful to know its exact hardness, as compared with pure iron. In any case, however, from the foregoing it is clear that nickel is a comparatively soft metal, and little harder than iron itself, so that its influence would not be expected to be great. It is therefore doubly strange to find that its addition to iron produces the effect met with, that is, a considerable increase of the elastic limit and tenacity; in fact, it is extraordinary in those specimens containing between about 8 per cent. and 22 per cent. of nickel. This is only another proof of the apparently anomalous behaviour of alloys. The Author considers that in this, as in other iron alloys, the effect of the added element is not so much direct but indirect, that is, nickel probably possesses its powerful influence owing to its action on the carbon or manganese present in the iron.

*Permeability.*—Pure nickel is stated by Moissan to be very permeable, and capable of occluding considerable volumes of gas; when used as an anode it can absorb 165 times its volume of hydrogen. He also states that the metal is not changed at the ordinary temperature by dry, but that it undergoes a slight change in damp, air. At a high temperature it takes different colours, like steel, but oxidizes slowly. Metallic nickel can be formed into a magnet, as with cobalt and iron. Although the two former are much less feebly magnetic than iron, these three are the only metals or elements which possess this quality of being able to form magnets.

*Mechanical Tests.*—Messrs. Henry R. Merton and Company, of London, have supplied the Author with specimens of pure cast and forged nickel made by the Westphalian Nickel Company, a company controlled by the Ferro-Nickel Company, of Paris, the nickel being produced from the New Caledonian ores. The following Table shows their exact physical qualities. The analysis

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showed 98·80 per cent. of Ni, and 0·75 per cent. Fe. Messrs. Merton inform the Author that a very large proportion of the nickel now produced is made from New Caledonian ores, probably at least 60 per cent. of the whole output.

The test-pieces were machined from bars 1 inch in diameter, and were tested as cast, and also as received in the forged condition. The diameter of the portions under stress was 0·7979 inch, and they were 2 inches in length.

CAST AND FORGED NICKEL (98·80 PER CENT. NI).

| | Elastic Limit. | Tensile Strength. | Elongation on 2 Inches. | Reduction in Area. | Appearance of Fracture. |
|---|---|---|---|---|---|
| | Tons per Square Inch. | Tons per Square Inch. | Per cent. | Per cent. | |
| Cast Test Bar, unannealed | 11 | 16·25 | 4·50 | 9·76 | Granular. |
| Forged Test Bar, unannealed | 14 | 32·20 | 45·50 | 57·04 | Fibrous silky. |
| Forged Test Bar, annealed . | 7 | 31·25 | 54·00 | 52·50 | Fibrous silky. |

Specific gravity of the "cast" nickel, 8·839.
" " " "forged" " 8·826.

The cast material showed a light-coloured crystalline, and the forged material a silky granular fracture. It may be added that the original bars, 1¼ inch in diameter, required, after nicking, twenty-seven blows of the sledge-hammer to produce fracture of the cast, and sixty-three blows, of the forged specimen.

Both cast and forged specimens filed much harder than iron of 99·80 per cent. purity. The cast nickel was the harder of the two, which is somewhat remarkable, seeing that its tenacity is only about half that of the forged nickel. It does not follow that high tenacity necessarily accompanies hardness, though it often is so.

To show the remarkable change produced by forging, a portion of the cast specimen which showed a breaking strength of 16 tons per square inch, and an elongation of 4·50 per cent., was hammered into strips ¾ inch wide by ¼ inch in thickness, and these were tested in the forged condition, and also after quenching at bright red or yellow heat. In both cases they bent double cold without cracking. In this respect, therefore, that is, as to the great increase of tensile strength in the forged as compared with the cast material, nickel differs considerably from iron. The tensile strength of pure cast and forged iron do not vary greatly, being

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about 17 tons or 18 tons per square inch. It is curious to note that annealing the forged nickel specimens, whilst not affecting the tenacity and ductility, reduces the permanent-set point 50 per cent., or to 7 tons per square inch. This is exactly the opposite effect to that produced by its presence in the nickel-iron alloys dealt with in the Paper, yet at the same time the tenacity was but little affected.

*Mechanical Tests on Pure Iron.*—As the main constituent of all the alloys or combinations dealt with in this Paper is Iron, the exact mechanical properties of this metal are added for reference and comparison. In the following Table the results given on almost pure iron (99·80 per cent. Fe), in both the cast and forged conditions, were obtained by Professor J. O. Arnold. For ready comparison the results obtained by the Author with pure nickel are repeated:—

| Material. | Condition. | Unannealed. | | | | Annealed. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Elastic Limit. | Tensile Strength. | Elongation on 2 Inches. | Reduction in Area. | Elastic Limit. | Tensile Strength. | Elongation on 2 Inches. | Reduction in Area. |
| | | Tons per Sq. In. | Tons per Sq. In. | Per cent. | Per cent. | Tons per Sq. In. | Tons per Sq. In. | Per cent. | Per cent. |
| Iron · {C 0·08 per cent. · Fe 99·80 per cent.} | Cast. | 14 | 20 | 16 | 34 | Not obtained. | | | |
| Iron · {C 0·08 per cent. · Fe 99·80 per cent.} | Forged. | 14 | 22 | 47 | 76 | 9 | 18 | 52 | 76 |
| Nickel {C 0·16 per cent. · Ni 98·80 per cent.} | Cast. | 11 | 16½ | 4½ | 9⅝ | Not obtained. | | | |
| Nickel {C 0·16 per cent. · Ni 98·80 per cent.} | Forged. | 14 | 32½ | 45½ | 57 | 7 | 31½ | 54 | 52⅝ |

*Methods of Adding Nickel in Iron Alloys and Varieties of the Metal Used.*—As regards the form of nickel used for alloying with iron, the metal itself, that is of 98 per cent. to 99 per cent. purity being so readily available, is preferably used, though ferro-nickel, containing various percentages of nickel, are also produced.

One other method still remains, that of introducing the nickel into the molten bath by means of nickel-oxide; this is practised on a large scale by one of the leading manufacturers of nickel steel. There should be no special advantage in it if the metallic nickel used is of the requisite purity. The oxide is added to the charge in the open-hearth furnace whilst decarbonization is proceeding,

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the carbon in the bath reducing the oxygen present. The Orford Copper Company offer this nickel-oxide at 1*s.* per lb. of nickel in the ore, which is combined with carbonaceous material and made up into briquettes before being added to the charge in the steel-melting furnace. Mr. E. F. Wood has devised[1] a method somewhat similar to the foregoing of adding nickel ore to iron during fusion in the open-hearth process.

The nickel used in these experiments was in the form of cubes manufactured by the Ferro-Nickel Company, and showed the following analysis:—

| C. | Si. | S. | Cu. | Sn. | As. | Fe. | Ni. |
|---|---|---|---|---|---|---|---|
| Per cent. 0·16 | Per cent. 0·09 | Per cent. 0·016 | Per cent. 0·11 | Per cent. 0·11 | Per cent. 0·11 | Per cent. 0·60 | Per cent. 98·80 |

As regards the nickel percentage in other nickel products, it may be interesting to state that Wharton's grain nickel showed 99·39 per cent.; Martino's disk metal 99·06 per cent.; Orford Company's nickel (produced exclusively by the dry process from Canadian pyrrhotite ores) 99·23 per cent.

The Ferro-Nickel Company of Paris state that pure nickel when hot oxidizes rapidly when exposed to air, and that it is not therefore possible to forge it without oxidation occurring. All specimens of pure nickel must be cast in closed vessels, and covered immediately after casting in charcoal.

As regards the best form of nickel to be used in producing nickel-iron alloys or steel, the Author was recently asked to make a research on this point, and there were submitted to him two varieties of nickel, viz., that produced by the Mond process, and ordinary nickel known as "Thompson's," produced at the Orford Company's Works, U.S.A., from Canadian ore or matte obtained at Sudbury.

The following Table gives details of the tensile and other tests, and it will be seen that notwithstanding the slightly higher percentage of nickel in the Mond material, the results differ but slightly. The composition of each material as regards carbon, nickel, and other contents being similar, the information now furnished may be of considerable practical value. In order to thoroughly test the qualities of the two alloys, test-bars of both 0·25 inch and 0·50 inch area were prepared.

[1] *American Manufacturer*, August 5th, 1892.

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| | | C. | Si. | S. | Fe. | Cu. | Co. | Ni. |
|---|---|---|---|---|---|---|---|---|
| Analysis per cent. Metallic Metal | Mond . . | 0·05 | none | 0·006 | 0·18 | none | none | 99·8 |
| | Thompson . | 0·16 | 0·09 | 0·016 | 0·60 | Cu. Sn. As. 0·11 | | 98·8 |

| Alloy. | Area. | Treatment. | Elastic Limit. | Tensile Strength. | Elongation on Two Inches. | Reduction of Area. | Forged Bending Tests. | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Unannealed. | Annealed. |
| | Ins. | | Tons per Sq. In. | Tons per Sq. In. | Per cent. | Per cent. | | |
| Mond— C, 0·25; Si, 0·06; S, 0·05; P, 0·04; Mn, 0·75; Ni, 2·90 per cent. | 0·25 | Unannealed | 27 | 40·50 | 24·5 | 59·32 | Bent double unbroken | Bent double unbroken |
| | 0·25 | Annealed | 24 | 36·00 | 32·0 | 56·56 | | |
| | 0·50 | Unannealed | 28 | 41·50 | 24·5 | 46·06 | | |
| | 0·50 | Annealed | 26 | 35·50 | 34·5 | 54·88 | | |
| Thompson— C, 0·26; Si, 0·05; S, 0·04; P, 0·04; Mn, 0·75; Ni, 2·90 per cent. . . . | 0·25 | Unannealed | 29 | 42·50 | 23·5 | 50·00 | Bent double unbroken | Bent double unbroken |
| | 0·25 | Annealed | 23 | 35·00 | 27·5 | 49·52 | | |
| | 0·50 | Unannealed | 29 | 45·50 | 20·5 | 46·26 | | |
| | 0·50 | Annealed | 22 | 35·50 | 32·5 | 51·10 | | |

*Production of the Author's Specimens.*—A bar 2½ inches square and about 30 inches in length was cast of each mixture, also a set of bending bars and fluidity strips. The various and increasing additions of nickel were added to molten iron, as free as possible from carbon and silicon, and containing about 0·70 per cent. of manganese.

The series comprises fourteen sets of specimens, and commences with specimen A containing 0·27 per cent. nickel, rising to specimen N containing 49·65 per cent. nickel. The following Table

| Specimen Mark. | Actual Analysis. | | | | | | Intended Percentage of Ni. |
|---|---|---|---|---|---|---|---|
| | C. | Si. | S. | P. | Mn. | Ni. | |
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | |
| A | 0·19 | 0·31 | 0·10 | 0·09 | 0·79 | 0·27 | 0·25 |
| B | 0·14 | 0·20 | .. | .. | 0·75 | 0·51 | 0·50 |
| C | 0·13 | 0·23 | .. | .. | 0·72 | 0·95 | 1·00 |
| D | 0·14 | 0·21 | 0·08 | 0·07 | 0·72 | 1·92 | 2·00 |
| E | 0·19 | 0·20 | .. | .. | 0·65 | 3·82 | 4·00 |
| F | 0·18 | 0·31 | .. | .. | 0·65 | 5·81 | 6·00 |
| G | 0·17 | 0·28 | 0·11 | 0·08 | 0·68 | 7·65 | 8·00 |
| H | 0·16 | 0·20 | .. | .. | 0·86 | 9·51 | 10·00 |
| I | 0·18 | 0·22 | .. | .. | 0·93 | 11·39 | 12·00 |
| J | 0·23 | 0·24 | 0·11 | 0·05 | 0·93 | 15·48 | 16·00 |
| K | 0·19 | 0·27 | .. | .. | 0·93 | 19·64 | 20·00 |
| L | 0·16 | 0·30 | .. | .. | 1·00 | 24·51 | 25·00 |
| M | 0·14 | 0·38 | .. | .. | 0·86 | 29·07 | 30·00 |
| N | 0·16 | 0·31 | 0·08 | 0·06 | 1·08 | 49·65 | 50·00 |

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gives the full analyses of the whole series, also the percentages of nickel aimed at.

In each experiment the molten alloy was poured into a cast-iron mould of the size mentioned above. As the addition of nickel, like chromium and tungsten, but unlike silicon and aluminium, does not confer soundness, sufficient aluminium was added to obtain ingots free from blowholes, also a certain percentage of manganese. In the entire absence of manganese it is not easy to produce sound and readily forgeable bars, the ingots being somewhat red-short. The Author would have preferred to omit it, as no doubt this element, although present in comparatively small amounts, does influence the physical properties, but this does not prevent a comparison between the various specimens, as their manganese contents are uniform. The Author's efforts to keep the carbon low were successful, and this is the great "disturbing" element. In other words, if the carbon exceeds about 0·15 per cent., its presence has considerable effect. Even the small percentage occurring in the specimens now described, averaging 0·17 per cent., is not by any means a negligible quantity, but in the present series, which represents results obtained chiefly from unquenched steel, the effect upon tenacity can only be slight. It is not easy to produce a series of test specimens of such considerable range, as has been done in the present instance, and with a uniformly low carbon percentage, but this having been accomplished, the results may be taken as well illustrating the effect of nickel upon iron.

No decrease of fluidity appeared in the alloys containing up to 1 per cent. nickel, but after this and up to 10 per cent. there was certainly a diminution; upon exceeding 10 per cent. the fluidity seemed to again increase, and to decrease again when passing about 18 per cent.

The important point that nickel does not produce soundness was very clearly brought out, and unless aluminium had been added to the fluid metal, the resulting castings would have been unsound and useless. It would appear, therefore, that nickel in this respect possesses a similar characteristic to that of iron. If molten iron is required free from oxygen or occluded gases, a reducing agent must be used. The producers of nickel found this necessary many years ago, and one maker kept for a long time his special secret, which enabled him to attain this object. Eventually the reducing agent was discovered to be magnesium; in a similar manner the elements aluminium and silicon have been of service for absorbing or reducing the oxygen present in molten iron.

*Condensed or Key-Table of Tests.*—The general physical properties

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KEY TABLE OF THE VARIOUS TESTS DESCRIBED IN THE PAPER.

Detailed information regarding A will be found in Table I, Appendix III, and Fig. 1, Plate 1; B in Table IV, Appendix III, and Fig. 5, Plate 1; C in Table II, Appendix III, and Fig. 2, Plate 1; D in Table II, Appendix III, and Fig. 3, Plate 1; E on page 43.

| Specimen Mark. | A. Analysis. | | | A. Unannealed Test-bars. Load in Tons per Square Inch. | | | | A. Annealed Test-bars. Load in Tons per Square Inch. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | C. | Mn. | Ni. | Elastic Limit. | Breaking Load. | Elongation. | Reduction of Area. | Elastic Limit. | Breaking Load. | Elongation. | Reduction of Area. |
| | | | | Tons. | Tons. | Per cent. | Per cent. | Tons. | Tons. | Per cent. | Per cent. |
| A | 0·19 | 0·79 | 0·27 | 19 | 31 | 35 | 56 | 20 | 28 | 37 | 52 |
| B | 0·14 | 0·75 | 0·51 | 20 | 30 | 36 | 62 | 21 | 27 | 41 | 63 |
| C | 0·13 | 0·72 | 0·95 | 25 | 33 | 31 | 53 | 20 | 27 | 41 | 63 |
| D | 0·14 | 0·72 | 1·92 | 26 | 34 | 33 | 55 | 22 | 31 | 36 | 53 |
| E | 0·19 | 0·65 | 3·82 | 28 | 37 | 30 | 54 | 25 | 33 | 35 | 55 |
| F | 0·18 | 0·65 | 5·81 | 28 | 41 | 27 | 40 | 28 | 37 | 33 | 51 |
| G | 0·17 | 0·68 | 7·65 | 31 | 49 | 26 | 42 | 30 | 45 | 26 | 41 |
| H | 0·16 | 0·86 | 9·51 | 42 | 85 | 9 | 18 | 32 | 56 | 2 | 2 |
| I | 0·18 | 0·93 | 11·39 | 65 | 94 | 12 | 24 | 45 | 89 | 12 | 26 |
| J | 0·23 | 0·93 | 15·48 | 55 | 94 | 3 | 2 | .. | 68 | 1 | 1 |
| K | 0·19 | 0·93 | 19·64 | 47 | 91 | 7 | 6 | 45 | 87 | 5 | 4 |
| L | 0·16 | 1·00 | 24·51 | 32 | 77 | 13 | 14 | 25 | 78 | 14 | 8 |
| M | 0·14 | 0·86 | 29·07 | 25 | 38 | 33 | 44 | 16 | 37 | 48 | 51 |
| N | 0·16 | 1·08 | 49·65 | No test made | | | | 15 | 36 | 49 | 53 |

| Specimen Mark. | B. Load in Tons per Square Inch. Forged Compression Tests (Unannealed Material). | | B. Cast Compression Tests (Annealed Material). | | C. Cast Bending Strips. | | D. Forged Bending Strips. | | E. Corrosion Tests on Forged Materials. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Elastic Limit. | Shortening Per Cent. by 100 tons. | Elastic Limit. | Shortening Per Cent. by 100 tons. | Unannealed. Bent to. | Annealed. Bent to. | Unannealed. Bent to. | Annealed. Bent to. | Loss in Grams. | Loss. |
| | Tons. | Per cent. | Tons. | Per cent. | | | | | | Per cent. |
| A | 22 | 50 | .. | .. | 18° | 154° | Double | Double | .. | .. |
| B | 22 | 50 | .. | .. | 29° | 80° | Double | Double | .. | .. |
| C | 20 | 49 | .. | .. | 91° | 85° | Double | Double | 2·003 | 3·23 |
| D | 27 | 47 | .. | .. | 150° | Double | Double | Double | .. | .. |
| E | 28 | 41 | .. | .. | 24° | 100° | 90° | Double | 1·611 | 2·95 |
| F | 40 | 37 | .. | .. | 11° | 71° | Double | Double | .. | .. |
| G | 40 | 33 | .. | .. | Nil | 41° | 26° | 89° | 1·581 | 2·77 |
| H | 70 | 3 | .. | .. | 2° | 8° | 28° | 5° | .. | .. |
| I | 100 | 1 | U66 | 5 | 3° | 9° | 22° | 3° | 1·390 | 2·60 |
| | | | A57 | 3 | | | | | | |
| J | 80 | 1 | .. | .. | 2° | 11° | No test | made | .. | .. |
| K | 80 | 3 | .. | .. | 2° | 3° | 19° | 17° | .. | .. |
| L | 50 | 16 | .. | .. | 12° | 10° | No test | made | 0·118 | 1·33 |
| M | 20 | 41 | .. | .. | 163° | 64° | Double | Double | 0·759 | 1·47 |
| N | No test made | | .. | | 53° | 19° | No test | made | .. | .. |

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including analyses, permanent-set points, breaking loads, elongations, reductions in area, bending angles of cast and forged bending bars, compression tests, specific gravities, and corrosion results are shown in the Key Table on page 12. The full and more detailed results are to be found in the main Table No. I, Appendix III, and the respective Tables devoted to the particular tests.

## Cast Nickel—Iron Alloys.

Although the Author has devoted more particular attention to the properties and behaviour of the forged nickel-steel alloys, he has also obtained considerable data regarding their properties in the cast condition, both in the unannealed and annealed state.

An excellent Paper on the Properties of Cast Nickel-Iron Alloys was prepared in 1896 by a special committee of the Berlin Society for the Promotion of Industry under the presidency of Dr. Wedding, and reported upon by Professor M. Rudeloff. The Author believes that a satisfactory account of this important research work has not appeared in any publication in England; he therefore gives a full abstract in Appendix I, as he desires to make the Paper as useful and complete as possible as to the various experimental work which has been done, not only by himself, but by others, on nickel-iron alloys.

*Appearance of the Fracture of Cast Material.*—Dealing first with the appearance of the fractures of the Author's specimens in their cast condition, these were found to be as shown in the following Table, in which is also given the specific gravity of the various cast nickel-iron alloy specimens.

| Specimen. | C. | Ni. | Appearance of Fracture. | Specific Gravity in Cast State. |
|---|---|---|---|---|
| | Per cent. | Per cent. | | |
| A | 0·19 | 0·27 | Very mild granular fracture | 7·691 |
| B | 0·14 | 0·51 | " " " | .. |
| C | 0·13 | 0·95 | Mild " " | 7·785 |
| D | 0·14 | 1·92 | " " " | .. |
| E | 0·19 | 3·82 | Mild fracture, but harder and closer grain than preceding ones | 7·777 |
| F | 0·18 | 5·81 | Rather coarse fracture | .. |
| G | 0·17 | 7·65 | Fibrous tearing fracture with granular centre | 7·743 |
| H | 0·16 | 9·51 | Small grain fracture | .. |
| I | 0·18 | 11·39 | Much closer, harder grain | .. |
| J | 0·23 | 15·48 | Fibrous tearing fracture | 7·752 |
| K | 0·19 | 19·64 | Very dry | .. |
| L | 0·16 | 24·51 | Dry, harsh fracture | 7·810 |
| M | 0·14 | 29·07 | Fibrous tearing | 8·054 |
| N | 0·16 | 49·65 | Soft fibrous tearing fracture | .. |

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*Cast Bending Bars.*—Whilst the Author has not prepared any tensile bars of the cast material, Fig. 2, Plate 1, shows the bending qualities of both unannealed and annealed cast material, thus showing their relative ductility to each other in these respective conditions. From these a relative comparison can be readily made with bending tests of forged nickel-steel. The results in these cast specimens are somewhat irregular, owing to the difficulty of obtaining satisfactory and sound cast bending strips of so small a section.

Nevertheless, the effect of the gradually increasing percentages of nickel is clearly brought out, and it will be seen that only in certain of the specimens does its influence appear to have been serviceable by increasing their ductility. In fact, up to about 2·50 per cent. nickel, the bending angles do not appear to be higher than with the Author's other alloys. From about 2·50 per cent., usually a critical point in most iron alloys, to about 6 per cent. nickel, the bars certainly show greater bending angles than in any other iron alloys. Specimens G to K (7 per cent. to 19 per cent. Ni) are quite brittle, which is remarkable in view of their low contents of carbon. After exceeding about 19 per cent. there is a considerable return of ductility; in fact, after about 30 per cent. the material appears to show quite as high bending angles as the specimens containing 2·50 per cent. and under.

The results of the annealed specimens follow those of the unannealed to a considerable extent. Annealing does not seem to have so great an influence as in other alloys—in fact, apparently little or none—upon the material within the comparatively brittle zone—that is, about 7 per cent. to 19 per cent. As regards those alloys containing more than 19 per cent. nickel, this treatment positively reduces the bending angle, as will be seen from specimens L, M, and N (24 per cent. to 49 per cent. Ni). It must be borne in mind that reference is here made to the cast material, the forged material probably differs to some extent.

The presence of a brittle percentage zone is remarkably like the behaviour of manganese-iron alloys. In the latter, this zone occurs between about 4 per cent. and 7 per cent. (in the nickel-iron alloys it is between about 7 per cent. and 18 per cent.), and as the carbon increases the brittleness and hardness is more marked.

Generally speaking, the qualities of the cast material may to a considerable extent be accurately judged by comparing the same percentage material in its forged condition. In other words, the results of the forged material indicate that the cast material, though not so ductile, possesses corresponding qualities. This is not always the case with other iron alloys.

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*Hardness of the Cast Specimens.*—Specimens A to D (0·27 per cent. to 1·92 per cent. Ni) were quite soft. F (5·81 per cent. Ni) showed an increase of hardness. G (7·65 per cent. Ni) could be readily filed, though very stiff. H (9·51 per cent. Ni) about the same as G; I (11·39 per cent. Ni) was still harder. J and K (15·48 per cent. and 19·64 per cent. Ni) were the hardest specimens of the series, but could be filed. L (24·51 per cent. Ni) showed a considerable diminution in hardness. M and N (29·07 per cent. and 49·65 per cent. Ni) were quite as soft as those specimens forming the first portion of the series. The behaviour within the hard and comparatively brittle zone is very curious. The Author found in his manganese-steel specimens that as regards the brittle zone the material cannot be filed; it appears to be practically as hard as chilled iron. The nickel specimens within the hard or brittle zone can be machined with comparative ease as compared with manganese steel, yet they show higher resistance under compression. It will be understood how difficult is the whole subject of alloys when such apparent anomalies are met with. It must, however, be remembered that in the manganese-steel in question the carbon was somewhat higher.

*Magnetic Susceptibility of the Cast Material.*—With the exception of M (29·07 per cent.) the whole of the specimens were exceedingly magnetic. M (29·07 per cent.) was only slightly attracted in bulk, but small fragments were easily picked up by the magnet. The specimens L (24·51 per cent.) and N (49·65 per cent.) were both very magnetic. It is therefore curious to find this particular specimen, M, showing so marked a difference. The cast bending bars of M showed the same property, but the forged specimens of the same material were strongly attracted, whether in the unannealed or annealed condition. In all cases, however, the specimens were magnetic, and the behaviour of M cannot be in any way compared for example to that of manganese steel.

## Forged Nickel—Iron Alloys.

The cast bars prepared as described were each 2½ inches square and about 30 inches in length, they were carefully heated in an ordinary furnace, and were then cogged under the steam-hammer into rough bars or billets about 1½ inch square, and finally, after again being re-heated, rolled into bars 1¼ inch in diameter, and about 7 feet to 8 feet in length. No special difficulty was met with in reducing the ingots, care being used during the heating process. A portion of the bar was retained in its unannealed

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condition, the remainder being annealed in the usual manner. From each bar 1¼ inches in diameter were prepared the following sets of test specimens:—

No 1.—Bending bars or strips, both from material in the unannealed and annealed condition, each ¾ inch wide, $\frac{3}{16}$ inch thick, and 4½ inches in length. The results are shown below and in Fig. 3, Plate 1.

No. 2.—Bars of similar dimensions for welding tests. The results are shown on p. 41.

No. 3.—Bars of similar dimensions for water-quenching experiments. The results of these tests are given on p. 28.

No. 4.—Bars for ascertaining whether the material possessed self-hardening properties, 1¼ inch diameter × 3 inches long. The results are shown on p. 42.

No. 5.—Bars from material in the unannealed and annealed condition, 1¼ inch diameter, 6 inches long, and from which the finished tensile bars were prepared. The results are given in Table I, Appendix III, and in Fig. 1, Plate 1.

No. 6.—Bars for compression tests in the unannealed condition, ⅞ inch in diameter and 1¼ inch long, from which the finished

BENDING TESTS OF FORGED NICKEL-IRON ALLOYS, AND WATER-QUENCHED BARS.

Size of bar, 4½ inches × $\frac{13}{16}$ inch × ⅜ inch.

| Specimen Mark. | Analysis. | | Not Quenched | | Quenched at about 750° C. Bent— | Quenched at about 950° C. Bent— | Quenched at about 1250° C.[1] Bent— |
|---|---|---|---|---|---|---|---|
| | C. | Ni. | Unannealed. Bent— | Annealed. Bent— | | | |
| | Per cent. | Per cent. | | | | | |
| A | 0·19 | 0·27 | Double unbroken | Double unbroken | Double unbroken | 140° | 6° |
| B | 0·14 | 0·51 | Ditto | Ditto | Ditto | Double unbroken | 8° |
| C | 0·13 | 0·95 | Ditto | Ditto | Ditto | 84° | 1° |
| D | 0·14 | 1·92 | Ditto | Ditto | 63° | 92° | 3° |
| E | 0·19 | 3·82 | 90° | Ditto | 42° | 39° | 5° |
| F | 0·18 | 5·91 | Double unbroken | Ditto | 33° | 24° | 8° |
| G | 0·17 | 7·65 | 26° | 89° | 36° | 24° | 2° |
| H | 0·16 | 9·51 | 28° | 5° | 15° | 13° | 4° |
| I | 0·18 | 11·39 | 22° | 3° | 7° | 18° | 2° |
| J | 0·23 | 15·48 | No test | made. | | | |
| K | 0·19 | 19·64 | 18° | 17° | 27° | 30° | 6° |
| L | 0·16 | 24·51 | No test | made. | | | |
| M | 0·14 | 29·07 | Double unbroken | Double unbroken | Double unbroken | Double unbroken | 148° |
| N | 0·16 | 49·65 | No test | made. | | | |

[1] Sparkling welding heat 1,250° to 1,350° C.

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compression pieces were prepared. These results are shown in Tables IV and V, Appendix III, and Figs. 5 and 6, Plate 1.

No. 7.—Strips for corrosion tests $\frac{3}{16}$ inch thick, $\frac{1}{16}$ inch wide, $3\frac{1}{2}$ inches long. The results are given on p. 43.

No. 8.—Rods No. 5 B.W.G. for electrical conductivity tests. These results are shown in Table VII, Appendix III, and Fig. 9, Plate 1.

No. 9.—Rods for magnetic susceptibility tests, No. 5 B.W.G. These results are plotted in Fig. 8, Plate 1.

A considerable portion of the tests are also shown in the Key-Table on p. 12, and are given fully in the Main Table No. I and in the Diagrams on Plate 1.

*Appearance of Fracture of the Forged Unannealed Material.*—The character of the forged material used for the tensile and other tests is given in the following Table. The end of each of the bars, $1\frac{1}{4}$ inch in diameter, was broken on the anvil, and the character of the fracture observed, as well as the number of blows of the sledge-hammer required to cause fracture.

| Specimen. | Analysis. | | Blows required to produce Fracture. | | Appearance of Fracture (Unannealed Material). |
|---|---|---|---|---|---|
| | C. | Ni. | Before Nicking. | After Nicking. | |
| | Per cent. | Per cent. | | | |
| A | 0·19 | 0·27 | 15 | 14 | Very mild open grain, somewhat similar to that of wrought-iron. |
| B | 0·14 | 0·51 | 15 | 18 | Dark fibrous fracture, very similar to specimen A. |
| C | 0·13 | 0·95 | 15 | 14 | Mild tearing fracture, a decided change from B. |
| D | 0·14 | 1·92 | 15 | 10 | Mild tearing fracture, similar to C, close grain. |
| E | 0·19 | 3·82 | 15 | 3 | Rather fine, close, granular structure. |
| F | 0·18 | 5·81 | 15 | 5 | Dark granular. |
| G | 0·17 | 7·65 | 15 | 4 | Close tearing fracture. |
| H | 0·16 | 9·51 | 15 | 24 | Rather dry tearing fracture. |
| I | 0·18 | 11·39 | 15 | 20 | Rather dry harsh fracture. |
| J | 0·23 | 15·48 | 15 | 7 | Close hard-looking fracture. |
| K | 0·19 | 19·64 | 15 | 23 | Dry hard-looking fracture. |
| L | 0·16 | 24·51 | 15 | 7 | Close hard grain. |
| M | 0·14 | 29·07 | 15 | 9 | Granular, slight yellow tinge. |
| N | 0·16 | 49·65 | 15 | 10 | Granular, slight yellow tinge. |

The results show that, the presence of nickel is not marked by any pronounced appearance until specimen H is reached. From this to L the grain is much closer than that of ordinary steel.



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M and N possess quite a special fibrous fracture, and do not in any way resemble ordinary steel.

*Forged Bending Bars.*—These bars were $\frac{3}{4}$ inch wide, $\frac{3}{16}$ inch thick, and $4\frac{1}{2}$ inches long, and the tests given on p. 16 and in Fig. 3, Plate 1, were made both in the unannealed and annealed condition.

*Unannealed.*—Specimens A to F (0·27 per cent. to 5·81 per cent.) present but little difference, bending double cold. The bending angle, however, then rapidly diminishes, specimens H to K (9·51 per cent. to 19·64 per cent.) differing but little. As in the cast bending bar tests M (29·07 per cent.), however, shows a return of ductility equal to the specimens A to D.

*Annealed.*—The results are similar to those of the unannealed bars, and in the hard specimens H to K and the higher specimens L to N the same behaviour is noticed as regarding the cast bending bars and the tensile bars, apparently showing that the annealing treatment is of little, if any, benefit.

*Hardness of Forged Specimens.*— That none of the specimens were intractable to the tool is proved from the fact that the tensile test bars with Whitworth threads were readily prepared from the whole of the series. Specimens A to C inclusive were very soft; D, E, F and G, though stiff, could also be easily filed; H was harder; I could be filed, was hard and very stiff, but could be machined; J and K were about alike, being very hard, but could be filed; L resembled the two preceding specimens, except that there was a slight falling off in the hardness; M and N again approached the softness of the first specimens in the series.

These observations are specially interesting, as the hardness of nickel-iron alloys in the brittle zone (7 per cent. to 18 per cent.) is very peculiar. These specimens show an extraordinarily high elastic limit, tenacity, resistance to compression stress, can be machined (though not easily), and yet are much more readily filed than would be anticipated from the above-named qualities. Manganese steel alloys in the brittle zone ($3\frac{1}{2}$ per cent. to 8 per cent.), on the contrary, though in these alloys the carbon is higher, are very low in tenacity, and can neither be filed nor machined.

*Preparation of Test-Pieces and Method of Testing.*—The tensile bars, prepared with threaded ends, of the various unannealed and annealed specimens, were obtained by turning the forged bars, $1\frac{1}{4}$ inch in diameter, to the usual Whitworth test-bar dimensions, viz., 0·7979 inch in diameter, or 0·50 inch in area, the elongation being measured upon a length of 2 inches. The Whitworth

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testing-machine had been carefully checked with test-bars of ordinary steel, "pulled" on an ordinary lever machine, and the results obtained corresponded almost exactly.

In the Whitworth testing-machine, which the Author has used for a number of years, the elastic limit or yield point of ordinary tensile test-bars is obtained by carefully watching the pointer finger on the dial which indicates the stress. This pointer is exceedingly sensitive to the slightest "flow" in the test-bar under stress. But to prevent any possibility of error in these specimens the length of each test-bar was carefully determined before applying any stress, and then, after passing 10 tons to the square inch, it was taken out of the holder at each stress increment of 1 ton until a definite elongation of the test-bar occurred. The necessary measurements were taken by means of a Whitworth measuring machine capable of detecting without any special difficulty or care 0·01 per cent. elongation.

Although this method does not accurately give the true elastic limit—that is, with it the proportional elastic limit is not obtained—the yield point is readily obtained. In steel of high breaking load and high elastic limit, such as those obtained from specimens H to L, this method has been found to give more correct results than those obtained with the ordinary lever testing-machines.

*Elastic Limit.*—The elastic limit or set point of the various specimens is given in Table I, Appendix III, and in Fig 1, Plate 1. By elastic limit is meant, as regards these specimens, the true yield point—that is, when extension exceeds proportionality.

*Unannealed Specimens.*—In specimens A, B and C, probably also D (0·27 per cent. to 1·92 per cent.), the elastic limit, as compared with ordinary steel, appears very slightly influenced. From D (1·92 per cent. Ni) upwards there is, however, a marked rise until specimen I (11·39 per cent. Ni) is reached, when there is obtained the very high elastic limit of 65 tons per square inch in the unannealed and 45 tons in the annealed condition. Specimen J (15·48 per cent. Ni) does not differ materially from I; but in K (19·64 per cent. Ni) there is a marked falling off, and somewhat curiously the unannealed and annealed specimens possess about the same elastic limit. After passing K there is an extraordinary drop, specimen M (29·07 per cent. Ni) being but slightly higher than the first specimen A, which contained only 0·27 per cent. Ni.

*Annealed Specimens.*—In this condition the elastic limit points, as compared with the unannealed specimens, are reduced slightly as regards A (0·27 per cent. Ni) and B (0·51 per cent. Ni); but



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C, D and E (0·95 per cent., 1·92 per cent., and 3·82 per cent.) are reduced 10 per cent. to 15 per cent. It is curious that F (5·81 per cent.) and G (7·65 per cent.) appear to be but little affected. H (9·51 per cent.), I (11·39 per cent.) and J (15·48 per cent.) are lowered. Upon reaching specimen L (24·51 per cent.), annealing is seen to have very considerably reduced the elastic limit, and this remark also applies to specimen M (29·70 per cent.). Generally speaking, annealing does not seem to have the same powerful influence which it has upon ordinary steel, a point which has been fully recognized and taken advantage of for practical purposes by those manufacturing carbon-nickel steel.

The addition of nickel, either by conferring greater homogeneity, or by some particular combination with the iron or carbon present, or both, appears to confer properties upon the alloy equivalent to an annealing, or if annealing be employed, to reduce the stress produced by forging; it does this without injuring or seriously lowering the elastic limit. In this respect, therefore, its presence is of considerable practical utility.

*Tensile Strength.*—These results are tabulated in the Key-Table on p. 12.

*Unannealed Specimens.*—Specimens A, B and C (0·27 per cent. to 0·95 per cent.) possess similar tenacity, but each successive increase of nickel adds to the tensile strength up to specimens I (11·39 per cent.), J (15·48 per cent.) and K (19·64 per cent.), in both of which the maximum tenacity of 94 tons per square inch is reached. These results are remarkable, as the three specimens show a range of variation in the percentage of nickel of no less than 8 per cent. L (24·51 per cent.) possesses also a high tenacity; but a further increase of 5 per cent. in the nickel (M, 29·07 per cent.) shows an extraordinary drop of about 50 per cent., the breaking stress not being much higher than the early specimens A and B (0·27 per cent. and 0·51 per cent.).

*Annealed Specimens.*—Annealing somewhat reduces the tensile strength, but much less than in ordinary carbon steel; in fact, the effect of annealing is very slight as regards specimens I, J, K and L (11·39 per cent. to 24·51 per cent.), each possessing very high tenacity. This fact is of considerable practical importance, and is perhaps one of the chief factors in the advantage of using nickel steel for certain special purposes. It would appear, therefore, that the benefits of annealing can be obtained, at any rate in these higher percentage alloys and probably in harder carbon steel containing nickel, without reducing, or only slightly so, the higher elastic limit or tenacity which they possess. Thus

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articles of irregular section can be relieved of their internal strains without having their tenacity lowered to any considerable extent. This does not apply, or only to a much less degree, to very mild steel containing nickel, and in which the effect of this metal is not so marked, except perhaps by conferring increased toughness.

*Elongation.*—These results are shown in the Key-Table on p. 12.

*Unannealed Material.*—Specimens A (0·27 per cent.) and B (0·51 per cent.) possess similar elongation to mild steel; C (0·95 per cent.) shows a slight falling off. There is then a gradual diminution in ductility. This is not very marked in specimen E (3·82 per cent.). F and G show further reductions, but on reaching H (9·51 per cent.) the fall is very considerable, the elongation being now only 9 per cent. J presents the minimum elongation, there is afterwards a rapid rise, and M (29·07 per cent.) possesses nearly the same ductility as the four earlier specimens A to D ( 0·27 per cent. to 1·92 per cent.).

*Annealed Material.*—Specimens A to G (0·27 per cent. to 7·65 per cent.) show somewhat irregular results, though on the whole annealing slightly improves the ductility. H to L (9·51 per cent. to 24·51 per cent.) show but little change, the difference, though small, being against annealing. M (29·07 per cent.) and N (49·65 per cent.) then follow the behaviour of, in fact are superior to, mild steel, the increase in elongation being very marked.

*Reduction of Area.*—These results are shown in the Key-Table on p. 12. Increasing percentages of nickel produce similar effects to those noticed as regards elongation. Here again annealing seems to produce but little effect, though in one or two of the specimens between H and L (9·51 per cent. and 24·51 per cent.) a slight diminution is perceptible. These may be due to experimental errors, though the results of the bending bars confirm the behaviour noticed. It must not be thought, without more exact information, that this or previous similar remarks regarding elastic limit and tenacity indicate that the annealing of nickel steel can be abandoned, because in several of the specimens now under consideration, this behaviour only relates to the special and experimental products principally within the brittle zone. Such products are not likely to be met with in ordinary practice, but the behaviour is noteworthy and may eventually help to throw considerable light upon what occurs in ordinary steel undergoing heat treatment.

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*Summary of Results upon the Tensile Tests.*—In reviewing the effect of nickel upon the various properties noticed it must be borne in mind that the results relate to alloys in which the carbon is low, of about the same amount as met with in mild steel. Consequently the properties of the specimens can only be taken to apply to products of similar composition and analysis.

Whilst specimen I (11·39 per cent. Ni) apparently possesses such a high tenacity and satisfactory elongation, it should be remembered that statical tests are not always an absolute index to the quality of steel, for the Key-Table on p. 12 shows, at the end of the line devoted to the tests of that particular specimen, that, notwithstanding the exceedingly high elongation, 12 per cent., that is, comparatively high when it is considered that the tenacity of the bar reaches the high figure of 94 tons per square inch, the bending bars, both cast and forged, possess but little ductility, the highest bend, that of the unannealed specimen, being only 22°.

As already pointed out, it is probable that the special advantage of the use of nickel is due not so much to the properties it confers upon iron in carbonless, or nearly carbonless, iron alloys, but to its modifying influence upon iron in the presence of carbon when it probably forms a special carbide of nickel. In the latter case it is hardly probable that high percentages of nickel will be required for ordinary uses to which steel is now applied. This theoretical opinion can only be accurately determined by the preparation of, say, ten specimens to each of the Author's nickel percentages, the carbon varying, say, by tenths. This would mean the production of about 140 different specimen alloys. As each of these specimens would require about 500 to 600 separate tests of various kinds, it will be seen that the work would require close application to even complete it in a lifetime. The Author gives this illustration to show the difficulty attending a complete solution of alloy questions. It ought also to show how exceedingly careful each experimenter should be in describing a new alloy or product. No one specimen means finality or is any indication of what a definite arrangement of other proportions may give.

*Compression Tests.*—The Author has always found in his various sets of alloy experiments, that considerable information can be gained as to the properties of the different specimens by submitting them to compression, a form of test often neglected, and these nickel-iron alloys form no exception. The exact qualities of the forged material are brought out in a very clear and interesting manner.

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The test-pieces were 0·7979 inch diameter or 0·50 inch area, and 1 inch in height. The yield or permanent set point was noted, as well as the total shortening in length produced by the application to the specimen of a load equal to 100 tons per square inch. The yield point was determined in a specially careful manner, similar to that described for the tensile bars, the test-piece being taken out of the machine at each increment of 10 tons per square inch, until a set was perceptible in the Whitworth measuring machine. The results of these tests are given in Figs. 5 and 6, Plate 1, and in Tables IV and V, Appendix III.

These compression tests have only been made on the forged specimens, and with unannealed material. In view of the comparatively slight effect of annealing upon the elastic limit in the tensile bars, it was not thought necessary to prepare another set in the annealed condition.

Dealing first with the elastic limit, or point where deformation was first noticed, the effect of the added element, nickel, follows in compression nearly the same line as the results obtained upon the elastic limit of the unannealed tensile test-bars. This is shown by the red and blue lines in Fig. 6, Plate 1.

Some noteworthy results are obtained, specially in specimens I and J (11·39 per cent. and 15·48 per cent. of nickel respectively), in which the resistance to compression is extraordinarily high. These results are the more remarkable, in view of the low percentage of carbon present, but it must always be borne in mind that in these particular specimens the manganese was somewhat higher than in the alloys dealt with in the Author's previous Papers, and the carbon, though low, is not a negligible quantity. A still more curious point is that, notwithstanding the high resistance of these specimens to compression stresses, they are comparatively soft and can be machined, though not readily. The hardest carbon steel, that is, in the unquenched condition, would not show such a high resistance as specimen I, though if hardened it would not "set up" even the 1 per cent. shown by that specimen.

These results provide another proof of the importance of finding a less empirical method of defining the term hardness. If it were possible to describe hardness in the same manner as, for example, temperature, data of the highest practical importance would become available.

Generally, specimens A to E (0·27 per cent. to 3·82 per cent. Ni) do not show large variance in the resistance to compression stress; they are all comparatively soft, "set up," or shorten from 37 per cent. to 49 per cent. of their total length, and

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do not materially differ from mild steel. Specimen F (5·81 per cent.), whilst shortening nearly as much as these previous specimens, shows a decided increase in its yield point; this rises from 28 tons in specimen E to 40 tons in F. The latter, with only about 2 per cent. higher nickel than present in E, is the commencement of a remarkable change in physical properties. Specimen H (9·51 per cent.) offers the very high yield point of 70 tons, shortens 3·23 per cent., whilst the next specimen, I (11·39 per cent.), containing only 2 per cent. more of nickel, apparently possesses no definite set point, even the full load of 100 tons per square inch shortening it but 1·05 per cent., or but 0·01 inch. This behaviour is most curious and phenomenal. Naturally the question occurs, why should two soft metals like iron and nickel[1] alloyed in these particular proportions give apparently such anomalous results? An alloy of manganese, a hard metal, and iron, a soft metal, alloyed in similar proportions, behaves almost exactly in the opposite manner, and with the same low percentage of carbon present, would probably shorten at least 20 per cent. under the same load. Specimen J (15·48 per cent.), although also showing very high resistance, is decidedly less than I, and in K (19·64 per cent.) there is still further reduction. After passing about 23 per cent. nickel there is a gradual return of similar softness to that of the earlier specimens, and M (29·07 per cent.) shortens 41 per cent. The results given in Table V, Appendix III, form therefore a very interesting curve in Fig. 5, Plate 1, which brings out clearly the effect produced by the varying and increasing additions of nickel to iron. In Fig. 6, Plate 1, is also given an interesting comparison between the yield points under tensile and compression stresses. It is remarkable to note how closely these two results agree, in which respect this material considerably differs from some of the Author's previous series of alloys.

In view of the low percentage of carbon in all the specimens, this high resistance to compression stress is very noteworthy; but as pointed out elsewhere in the Paper, it must be borne in mind that in these alloys there is also present about 0·75 per cent. manganese, which is without doubt a considerable hardener of

[1] It must be borne in mind that Specimen I contains 0·18 per cent. carbon and 0·93 per cent. manganese; but the carbon, as the specimen is tested in the unquenched condition, has but little influence, and the manganese would not, in unquenched steel of similar carbon and manganese, possess a set point of more than 18 tons to 20 tons.

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iron, even in the presence of only 0·15 per cent. carbon, which is the average percentage in these alloys. As these specimens are tested in the unquenched condition, the hardening powers of carbon and manganese, whilst they must be considered, may be described rather as "latent." There is no doubt that as regards pure alloys of iron and nickel, that is, no carbon or other elements being present, or to only a small extent, the increase in resistance to stress, whether tensile or compression, as evinced either in high elastic limit or high tenacity, or high resistance to compression, would be considerable, and is a most remarkable property, apparently only possessed by these nickel-iron alloys. The Author regrets that he has not been able to add a Table of the comparative hardness of these various nickel alloys, as accompanied his other alloy experiments, and from which a comparison might have been drawn between this physical quality and the resistance of the alloys to compression and tensile stresses. There is at present no means of obtaining such comparison.

To whatever conclusion these remarkable results lead, it must be remembered that whilst nickel-iron alloys, that is, as regards those containing high percentages of nickel, such, for example, as specimens I and J, present extraordinarily high resistance to compression, they cannot be described as possessing hardness like that of carbon steel in its hardened condition. The causes at work to produce the resistance to compression noticed are entirely different to those met with in hardened carbon steel. Thus the whole of the tensile and compression test-bars have been machined from the original forged bars, and in the case of the former prepared with threaded ends to suit the Whitworth dies or holders, thus proving their comparative softness. To the tool, specimens I (11·39 per cent.) and J (15·48 per cent.) are much harder than specimens H (9·51 per cent.) and K (19·64 per cent.), and are not so quickly prepared; but their hardness would not, for example, compare with that of manganese-steel, which again cannot be compared to the hardness of hardened carbon steel. But it is certainly most remarkable to find in the presence of so small an amount of carbon, and also comparatively low in other elements, that the alloys of iron and nickel possess such extraordinary stiffness. When a compression bar such as I, containing 11·39 per cent. of nickel and only 0·93 per cent. of manganese, is practically unaffected by a load which would shorten ordinary mild steel containing the same percentage of carbon (0·18 per cent.) from 60 per cent. to 65 per cent., it is difficult to satisfactorily explain the behaviour of material within this brittle and

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hard zone (approximately 9 per cent. to 19 per cent.) of nickel-iron alloys.

The properties of the two chief metals in the alloy are known very exactly, or as regards nickel to a considerable degree. Both are quite soft and lacking in hardness as well as resistance to compression.[1] By combining them together in certain proportions, there results a new material having most extraordinary properties.

The combination produces results, too, that are apparently anomalous in the state of present knowledge. An alloy is obtained composed of two soft metals, the resistance of which to tensile stress is very high, even compared with hard carbon steel, that is, in its unhardened condition, and even with much hardened, or rather quenched, carbon steel. It is doubtful whether any specimen of carbon steel in its ordinary condition, that is, unhardened, has ever been known to give such a high tenacity, for example, as specimen I (11·39 per cent.), which in the unannealed condition possessed a tensile strength of 94 tons, and even in the annealed condition 89 tons per square inch. Yet these specimens to the machine tool or file in no way compare with the hardness of hardened carbon steel. If it had not been so the various machined specimens prepared for the Paper could not have been produced. If similar compression-pieces were prepared from material like I (11·39 per cent.) and hardened carbon steel, then tested by the application of a stress of, say, 200 tons to the square inch, the carbon steel would probably still remain unaffected, and the nickel steel of I composition would be shortened considerably. But this would not detract from the significance of a nickel iron alloy able to offer such extraordinary resistance as that met with by the Author. So far, too, no very satisfactory explanation can be offered as to why these results are obtained.

Experimenters can only leave this point with the surmise that nickel, in its remarkable toughening action upon iron, causes a very intimate combination of the molecular structure. This, perhaps, may be supported by the fact that nickel does not show any disposition to segregate in steel like other elements; in other words, it appears to be more intimately combined. But whilst this might satisfactorily explain the greater toughness, it does not explain the greater tenacity of the two soft metals when

[1] As will be seen from the tests on p. 7, the elastic limit of forged nickel is 14 tons per square inch (much higher than that of iron), but this is at once reduced 50 per cent., viz., to 7 tons, by annealing.

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combined.[1] Cast nickel-steel, as proved by the Berlin experiments described in Appendix I, does not either in the 8 per cent. or 16 per cent. percentages (unfortunately there is no specimen between these percentages at the specially interesting and critical point) indicate so great a change as met with in the Author's experiments. The Berlin cast specimens were probably lower in carbon and manganese than the Author's. The percentage of the former is not given, but the latter did not exceed 0·10 per cent. Unfortunately, as none of the specimens were forged, it is difficult to know what change would have been produced in the tenacity by that treatment.

*Bending and Water-Quenching Tests.*—Table II, Appendix III, and that on pp. 28–29, show the results of bending tests upon the nickel-iron alloys both in the unannealed and annealed conditions, the latter being accompanied by tests of the same material quenched from temperatures of 750° C., 950° C., and 1,250° C. respectively. In order to make the results clearer, these bending tests are also repeated on p. 16, which shows the effect of water-quenching upon the hardness of the various specimens of nickel-iron alloys.

Although the hardness, to the file, of the specimens seems to be little affected by the heat treatment and quenching, yet their ductility, as will be seen from p. 16, is largely reduced, with the exception of specimen M (29·07 per cent.) which, whether unannealed, annealed, or quenched from any of the three temperatures mentioned, seems to retain its special ductility. Specimens A (0·27 per cent.) and B (0·51 per cent.) are not greatly affected, but after these the ductility of the specimens, quenched even at the lowest point, 750° C., is considerably reduced. The whole of the specimens, with the exception of M (29·07 per cent.), seem very strongly influenced by quenching from the welding temperature, and this would also apply to all carbon steel, with the exception of the mildest qualities, say, 0·10 per cent. of carbon and under.

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[1] In nickel steel containing carbon of considerable percentages, probably above Arnold's saturation point (0·80 per cent. to 0·90 per cent), it would appear as if the carbon combination can be readily dissolved, for the Author has obtained specimens (in the forged condition) which, by annealing, have had the greater portion of their carbon precipitated as graphite, and the tenacity, instead of being 65 tons to 70 tons per square inch, drops to nearly one-third of that amount, or little more than that of pure iron. In other words, the nickel present, when not combined with the carbon or iron, or both, has little influence. The Author thinks that this is an important confirmation of his theory that the effect of nickel upon iron is indirect.

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EFFECT OF WATER-QUENCHING AT VARIOUS TEMPERATURES UPON THE DUCTILITY

| Specimen. | Analysis. | | | Not quenched. Bending Tests— | | No. 1 Treatment (about 750° C.) | | |
|---|---|---|---|---|---|---|---|---|
| Mark. | C. | Mn. | Ni. | Unannealed. | Annealed. | File Test. | Hardness Test. | Bending Test. Bent to— |
| | Per Cent. | Per Cent. | Per Cent. | | | | | |
| A | 0·19 | 0·79 | 0·27 | Double unbroken | Double unbroken | Could file though stiff | Would not scratch glass | Double unbroken Slightly cracked |
| B | 0·14 | 0·75 | 0·51 | Ditto | Ditto | Ditto | Ditto | Double unbroken |
| C | 0·13 | 0·72 | 0·95 | Ditto | Ditto | Easily | Ditto | Ditto |
| D | 0·14 | 0·72 | 1·92 | Ditto | Ditto | Could file, though stiff | Ditto | 63° Sound |
| E | 0·19 | 0·65 | 3·82 | 90° | Ditto | Ditto | Ditto | 42° Sound |
| F | 0·18 | 0·65 | 5·81 | Double unbroken | Ditto | Ditto | Ditto | 33° Sound |
| G | 0·17 | 0·68 | 7·62 | 26° | 89° | Comparatively easy | Ditto | 36° Sound |
| H | 0·16 | 0·86 | 9·51 | 28° | 5° | Could file, though stiff | Ditto | 15° Sound |
| I | 0·18 | 0·93 | 11·39 | 22° | 3° | Hard, but could file | Ditto | 7° Sound |
| J | 0·23 | 0·93 | 15·48 | | | No | tests | made |
| K | 0·19 | 0·93 | 19·64 | 18° | 17° | Could file, though stiff | Would not scratch glass | 27° Sound |
| L | 0·16 | 1·00 | 24·51 | .. | .. | No | tests | made |
| M | 0·14 | 0·86 | 29·07 | Double unbroken | Double unbroken | Filed quite easily | Would not scratch glass | Double unbroken |

No. 1 Treatment—Specimens heated to about 750° C.
No. 2 „ „ „ „ 950° C.
No. 3 „ „ „ „ 1,450° C.

N.B.—When considering the hardness tests it must not be overlooked that all these low, yet it is present in sufficiently high percentage to appreciably affect the physical

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ND HARDNESS OF THE VARIOUS SPECIMENS OF FORGED NICKEL-IRON ALLOYS.

| No. 2 Treatment (about 950° C.) | | | No. 3 Treatment (about 1450° C.) | | |
|---|---|---|---|---|---|
| File Test. | Hardness Test. | Bending Test. Bent to— | File Test. | Hardness Test. | Bending Test. Bent to— |
| Could file, though stiff | Would not scratch glass | 141° sound | Much harder than 1 and 2, could just file | Would not scratch glass | 6° Sound. |
| Comparatively easily | Sharp corner scratch glass | Double unbroken | Much harder than 1 and 2. Rather stiff | Ditto | 8° Sound. |
| Shade harder than 1 | Would not scratch glass | 84° Sound | Could file, though much harder than 2 | Ditto | 1° Sound. |
| Could file, though stiff | Ditto | 92° | Rather harder than 1 and 2, though could file fairly easily | Ditto | 3°. Part of bar fell to pieces in fire. |
| Could file, though rather hard | Ditto | 39° Sound | Much harder than 1 and 2, but could still file | Ditto | 5° Sound. |
| Harder than 1. Could file | Ditto | 24° Sound | Little harder than 2. Could file | Ditto | 8° Sound. |
| Rather stiffer than No. 1, could file fairly easily. | Ditto | 24° Sound | Rather harder than No. 2. Could file | Ditto | 2° Sound. |
| Could file, though stiff | Ditto | 13° Sound | Rather harder than Nos. 1 and 2. Could file | Ditto | 4° Sound. |
| Hard, but could file | Ditto | 18° Sound | Little harder than 1 and 2, but could still file | Ditto | 2° Sound. |
| Much harder than No. 1; could file | Ditto | 30° Sound | Little harder still, very difficult to file | Ditto | 6° Sound. |
| Filed quite easily | Ditto | Double unbroken | Filed quite easily | Ditto | 148° Roaky. |

(low red) and quenched in cold water.
(bright red) and quenched in cold water.
(sparkling welding heat) and quenched in cold water.

specimens contained about 0·70 per cent. manganese, and also that although the carbon is qualities of quenched material.

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*Comparison of Mechanical Tests on Various Alloys.*—To bring to a point of comparison the various alloys which the Author has produced during the last few years, Table III, Appendix III, and Fig. 4, Plate 1, have been prepared. From these it is possible to compare six sets of alloys of iron with silicon, aluminium, chromium, and nickel, also tungsten and copper. The latter are not shown in the diagram, the full results with these two alloys not being completed.

*Elastic Limit.*—From Fig. 4, Plate 1, it will be seen that in the first set, representing alloys of iron with six different elements, fairly constant in their percentage, viz., 0·24 per cent. to 0·40 per cent., and with the carbon not exceeding 0·19 per cent., that as regards elastic limit, the lowest is that of the silicon-steel alloy, followed by chromium, tungsten, aluminium, and nickel. The difference between any of these is not great, the copper steel alone showing a marked rise, namely, 4 tons higher than the next one below it, and 8 tons more than the silicon-iron alloy.

In the next set, representing 0·66 per cent. to 1·39 per cent. of foreign elements, similar behaviour is noticed, the copper showing a very much higher elastic limit than any of the others, or nearly 12 tons more. It must, however, be borne in mind that the copper is present in higher percentage, namely, 1·39 per cent., and the manganese is abnormal, viz., 2·01 per cent., but nevertheless, in view of the low carbon, not altogether sufficient to account for the great rise in elastic limit.

In the third set, representing 1·51 per cent. to 1·92 per cent. of foreign elements, the copper specimen being absent, the highest place is occupied by the silicon-iron alloy, the others being similar.

In the fourth set, representing about 2 per cent. to 2½ per cent. of foreign elements, the tungsten specimen, however, containing 3·40 per cent. of that element, and the nickel specimen 3·82 per cent. of nickel, the aluminium-iron alloy shows the lowest elastic limit, otherwise the other alloys vary but little.

In the last set, that is, containing about 5½ per cent. to 6 per cent. of foreign elements, the copper-iron alloy being absent, as it proved unforgeable, the nickel alloy shows the highest set-point.

*Tensile Strength.*—In the three earlier sets the copper-iron alloy possesses much the highest breaking strength, the others do not vary greatly.

In the fourth set the chromium-iron alloy shows the highest breaking strength, but the carbon present, being abnormally high, must also be taken into account. This also applies to the chromium alloy in the last set.

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The silicon alloy in the fifth set falls to the lowest breaking load, the tungsten, apart from the abnormal chromium-steel specimen, being the highest.

*Elongation.*—The first three sets of alloys do not widely differ, except that as regards the copper-iron specimen in the first set, this is decidedly lower than any of the others, but in the second set this difference is not so marked.

In the third set, the copper-iron alloy being absent, the elongations are remarkably alike, so that it would appear that, as regards this property, about 1½ per cent. of either silicon, aluminium, nickel, chromium, or tungsten, do not, in their respective effect upon iron, and in the presence of low percentages of carbon, vary considerably. In view of the great differences in the properties of the respective elements in question, this result is certainly surprising.

In the fourth set there is now wide divergence in the ductility. The nickel-iron and tungsten-iron alloys alone possess this property, the other alloys being very brittle.

*Reduction in Area.*—These results follow in a similar direction to those of the elongation tests.

*Bending Tests on the Forged Annealed Specimens.*—It is remarkable that the whole of the bars in the first four sets bent double cold, but, in the fifth set, only the chromium, nickel, and tungsten alloys behaved in this manner. It must be borne in mind that these specimens are only of small section, $\frac{3}{8}$ inch wide, and $\frac{3}{16}$ inch in thickness. Being also well annealed, their behaviour can only be taken to represent bars of this or similar thin section, but it is very curious to find that such a wide range of alloys, both as regards the character and percentage of the elements present in each series, possess apparently similar bending qualities. It is only another proof of the impossibility of generalizing in alloy work, and that very large sets of experiments must be made upon material in various forms and shapes, before drawing definite conclusions as to suitability for various practical applications.

*Bending Tests on the cast Material.*—The Table on the following page enables a comparison to be made between the bending qualities of cast nickel-iron alloys, and those of cast chromium, silicon, and aluminium-iron alloys.

*Compression Tests.*—Fig. 7, Plate 1, enables a comparison to be drawn between the compression tests of nickel-steel and chromium, silicon, and aluminium steels. It is remarkable to note the small difference between these various alloy steels up to about 5 per cent. of the special element characterizing each.

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*Magnetic Qualities of the Cast Material.*—The whole of the specimens, when tested with an ordinary magnet, were strongly attracted. Specimens I to L (11·39 to 24·51 per cent.) are no doubt much more susceptible to changes in magnetic condition than the remainder of the series, varying according to the heat treatment. The Author, however, is inclined to believe that with an absolutely pure alloy of iron and nickel, no carbon or manganese being present, the specimens would invariably be magnetic, no

COMPARISON TABLE OF BENDING TESTS ON CAST AND FORGED SILICON, ALUMINIUM, CHROMIUM AND NICKEL-IRON ALLOYS, IN THE UNANNEALED AND ANNEALED CONDITIONS. TO THIS IS ADDED AS COMPARISON TESTS ON COPPER AND TUNGSTEN ALLOYS.

| Steel. | Specimen Mark. | Analysis Per Cent. | | | | | | | Cast. | | Forged. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C. | Si. | Al. | Cr. | Ni. | Cu. | W. | Unannealed bent cold to— | Annealed bent cold to— | Unannealed bent cold to— | Annealed bent cold to— |
| Silicon . . | A | 0·14 | 0·24 | .. | .. | .. | .. | .. | .. | .. | .. | Double |
| Aluminium | A | 0·15 | .. | 0·38 | .. | .. | .. | .. | Double | Double | Double | ,, |
| Chromium . | B | 0·16 | .. | .. | 0·29 | .. | .. | .. | 93° | ,, | ,, | ,, |
| Nickel . . | A | 0·19 | .. | .. | .. | 0·27 | .. | .. | [1] 18° | 154° | ,, | ,, |
| Copper . . | O | 0·19 | .. | .. | .. | .. | 0·40 | .. | 72° | Double | ,, | ,, |
| Tungsten . | B | 0·15 | .. | .. | .. | .. | .. | 0·20 | 64° | ,, | ,, | ,, |
| Silicon . . | B | 0·18 | 0·73 | .. | .. | .. | .. | .. | .. | .. | .. | Double |
| Aluminium | C | 0·18 | .. | 0·66 | .. | .. | .. | .. | 88° | Double | Double | ,, |
| Chromium . | E | 0·12 | .. | .. | 0·84 | .. | .. | .. | 130° | 77° | ,, | ,, |
| Nickel . . | C | 0·13 | .. | .. | .. | 0·95 | .. | .. | 91° | 85° | ,, | ,, |
| Tungsten . | E/2 | 0·21 | .. | .. | .. | .. | .. | 0·81 | 31° | Double | ,, | ,, |
| Silicon . . | C | 0·19 | 1·60 | .. | .. | .. | .. | .. | .. | .. | .. | Double |
| Aluminium | F | 0·21 | .. | 1·60 | .. | .. | .. | .. | 28° | 133° | Double | ,, |
| Chromium . | G | 0·21 | .. | .. | 1·51 | .. | .. | .. | 15° | Double | ,, | ,, |
| Nickel . . | D | 0·14 | .. | .. | .. | 1·92 | .. | .. | 150° | ,, | ,, | ,, |
| Copper . . | I | 0·25 | .. | .. | .. | .. | 1·39 | .. | 2° | 55° | 65° | ,, |
| Tungsten . | G | 0·21 | .. | .. | .. | .. | .. | 1·49 | 18° | Double | Double | ,, |
| Silicon . . | D | 0·20 | 2·18 | .. | .. | .. | .. | .. | .. | .. | .. | Double |
| Aluminium | H | 0·24 | .. | 2·24 | .. | .. | .. | .. | 16° | 32° | Double | ,, |
| Chromium . | H | 0·39 | .. | .. | 2·54 | .. | .. | .. | 90° | [1] 21° | nil | ,, |
| Nickel . . | E | 0·19 | .. | .. | .. | 3·82 | .. | .. | 24° | 100° | Double | 90° |
| Copper . . | A/2 | 0·23 | .. | .. | .. | .. | 2·72 | .. | 6° | Double | 120° | Double |
| Tungsten . | H | 0·28 | .. | .. | .. | .. | .. | 3·40 | 23° | ,, | 110° | ,, |
| Silicon . . | H | 0·26 | 5·53 | .. | .. | .. | .. | .. | .. | .. | .. | nil [1] |
| Aluminium | I | 0·22 | .. | 5·60 | .. | .. | .. | .. | 2° | 4° | 15° [1] | 16° [1] |
| Chromium . | J | 0·77 | .. | .. | 5·19 | .. | .. | .. | nil | 3° | 3° | Double |
| Nickel . . | F | 0·18 | .. | .. | .. | 5·81 | .. | .. | 11° | 71° | Double | ,, |
| Copper . . | B | 0·16 | .. | .. | .. | .. | 4·40 | .. | 3° | 101° | no test | made |
| Tungsten . | I | 0·38 | .. | .. | .. | .. | .. | 7·47 | 6° | 41° | 84 | Double |

[1] Defective bars.

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matter what treatment, that is, within the ranges of ordinary temperature.

In order to thoroughly confirm the statements regarding the magnetic qualities of the cast material, the Author re-tested all the specimens, and there is not one of them which is not susceptible to magnetic influence. Specimen M, which probably possesses the least amount of magnetism, is, when tested in the ordinary way with a magnet, strongly attracted, whether in the unannealed or the annealed condition, and whether cast or forged.

*Magnetic Qualities of the Forged Material.*—Nickel-iron alloys present a number of anomalies, though these do not occur until reaching the higher percentages, about 17 per cent. and up to 25 per cent. Under and over these limits their behaviour does not differ materially from that of ordinary soft steel.

*Magnetic Qualities of Nickel.*—When considering the magnetic qualities of the metal itself, it may be said that pure nickel, unlike pure iron, is capable of being permanently magnetized to a notable degree, but the maximum of such magnetization is only from one-third to one-half that retained by hardened steel under similar conditions.

In a Paper entitled,[1] "The Magnetic Properties of an Impure Nickel," by Dr. J. Hopkinson, F.R.S., mention is made of a specimen, containing 95·15 per cent. of nickel, about 1 per cent. of copper, cobalt, and iron, and 1·17 per cent. carbon. He showed that the specimen upon which he experimented lost its magnetization at a temperature of about 310° C., and from this he inferred that such specimen showed that no great or sudden absorption or liberation of heat occurred with the accession of the property of magnetizability. There is no doubt that, whilst different in this and other respects from iron, there are nevertheless several points of resemblance between the metals nickel and iron as regards magnetic qualities, not the least interesting being the curious fact that the magnetic moment of nickel is increased by the addition of tungsten, as is that of iron. This has been described in a very interesting Paper by Messrs. Trowbridge and Sheldon on "The Magnetization of Nickel and Tungsten Alloys."[2] This increase is stated to be only small until the material was forged and rolled.

Mr. Joseph Wharton, of the American Nickel Works, Camden, N.J., in his excellent exhibit of nickel at the Chicago Exhibition, 1894, showed a considerable number of nickel-tungsten alloys, the

[1] Proceedings of the Royal Society, vol. xliv. p. 317.
[2] American Journal of Science, December, 1889, p. 462.



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latter element varying from 1 per cent. to 6 per cent. He also exhibited a ship's compass with the magnetic needle made of pure nickel in 1876, magnetized in that year and not since re-magnetized.

The Author has seen many statements regarding the absolute non-magnetic qualities of certain nickel-iron alloys, but as these have generally been unaccompanied by full analyses, it is not possible to state whether they really represent the actual qualities of pure alloys of iron and nickel. No matter how great the percentage of the foreign element in the iron alloy, if carbon is also present in any perceptible quantity its influence is very powerful. It is not, therefore, correct to judge the properties of such alloys unless the whole of its constituents are very exactly known and determined, and it should, therefore, be the aim of all experimenters to accompany their statements with the analysis of the metal which they are examining and describing. Important and interesting Papers are written concerning the behaviour of iron alloys without one word being mentioned as to the exact composition of the specimens being examined. The behaviour of a 25 per cent. nickel steel, containing, say, 0·20 per cent. carbon, is very different from that of a 25 per cent. nickel steel containing 1 per cent. of carbon; hence the necessity for great care in knowing the whole history of the specimen being examined.

Take, for example, the statements which have been given by several experimenters, that nickel-iron alloys can be made magnetic or non-magnetic at will. That may be so for an alloy of some particular composition, but does it apply to alloys almost entirely composed of nickel and iron? The Author made the following experiments upon his alloys: J, L, and M, containing respectively, 15·48 per cent., 24·51 per cent., and 29·07 per cent. nickel, and in each case about 0·17 per cent. carbon. A small bar specimen, $1\frac{1}{8}$ inch diameter, was taken from each of these three alloys and quenched in a freezing mixture composed of equal parts of calcium chloride, and ice, which reduced the temperature to 11° F. After immersion for 5 minutes they were tested for magnetic susceptibility and no change was detected, the specimens remained equally magnetic as before cooling. Further changes may possibly occur if very low temperatures are used, but these must evidently be very low, and out of the range of ordinary practical observation. In the absence of carbon, and perhaps other elements such as manganese, the Author is inclined to the view that iron-nickel alloys are, and will remain, constantly magnetic whatever may be the treatment within the ordinary

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ranges of temperature. To further test the point, and as it has been stated that by quenching 25 per cent. nickel steel in cold water it becomes non-magnetic, the Author took specimens of forged nickel steel L, containing 24·51 per cent. nickel and 0·16 per cent. carbon, and treated them in the manner described in the following Table.

EFFECT OF THERMAL TREATMENT UPON THE MAGNETIC SUSCEPTIBILITY OF 25 PER CENT. NICKEL-IRON ALLOYS ON FORGED STRIPS 1 INCH WIDE BY ¼ INCH THICK BY 3 FEET LONG.

| Mark on Sample. | Analysis. | | | | Heated to. | Magnetic Susceptibility. |
|---|---|---|---|---|---|---|
| | C. | Si. | Mn. | Ni. | | |
| | Per cent. | Per cent. | Per cent. | Per cent. | | |
| L/1 | 0·16 | 0·30 | 1·00 | 24·51 | Very low red heat, just above "blue" heat (probably about 580° C.) | Non-magnetic whilst hot, but, after being water-quenched at this heat, became very magnetic. |
| L/2 | .. | .. | .. | .. | Blood red (about 660° C.) | Ditto. |
| L/3 | .. | .. | .. | .. | Bright red (about 920° C.) | Ditto. |
| L/4 | .. | .. | .. | .. | Yellow heat (about 1,080° C.) | Ditto. |

In each case the specimen, after being heated to the temperature mentioned, was rapidly quenched in ordinary cold water.

It has been stated that 25 per cent. nickel steel becomes non-magnetic at 520° C., and remains so after being plunged at this heat into cold water, but the above experiments do not indicate this result, and the Author thinks the specimens must have also contained comparatively high percentages of carbon. From these results it would appear that, at any rate, low carbon nickel-steel of this particular high percentage remains unaffected by heat treatment, which is contrary to the views hitherto advanced.

The subject of the magnetic qualities of iron alloys has been dealt with in a very full and interesting Paper by Dr. J. A. Fleming, F.R.S., and Professor Dewar, F.R.S.,[1] on "The Changes Produced in Magnetized Iron and Steel by Cooling to the Temperature of Liquid Air."

Professor Barrett, F.R.S., has prepared a comprehensive diagram (Fig. 8, Plate 1) relating to the magnetic properties of specimens D (1·92 per cent. Ni), E (3·82 per cent.), I (11·39 per cent.),

[1] Proceedings of the Royal Society, vol. lx. p. 57.



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K (19·64 per cent.), and L (24·51 per cent.). Also as comparison a specimen of Bowling iron marked "B" containing only 0·03 per cent. of carbon. Also a further nickel-iron alloy (1449) containing 31·4 per cent. nickel, but at the same time 0·7 per cent. of carbon. The following Table shows the analyses:—

| Mark. | Analysis. | | | | | | |
|---|---|---|---|---|---|---|---|
| | C. | Si. | S. | P. | Mn. | Ni. | Fe. |
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| D | 0·14 | 0·21 | 0·08 | 0·07 | 0·72 | 1·92 | |
| E | 0·19 | 0·20 | .. | .. | 0·65 | 3·82 | |
| I | 0·18 | 0·22 | .. | .. | 0·93 | 11·39 | |
| K | 0·19 | 0·27 | .. | .. | 0·93 | 19·64 | |
| L | 0·16 | 0·30 | .. | .. | 1·00 | 24·51 | |
| Bowling iron B | 0·03 | 0·14 | 0·016 | 0·065 | 0·03 | .. | 99·60 |
| 1449 | 0·70 | .. | .. | .. | 0·82 | 31·4 | |

The decrease in magnetization as the percentage of nickel increases is thus brought out in a very clear manner by this research work of Professor Barrett.

Mr. C. E. Guillaume made an important communication to the Société d'Encouragement pour l'Industrie Nationale in March last regarding the magnetic and dilatation qualities of various nickel-iron alloys.

A further similar research was communicated at the same time by Mr. Eugene Dumont.

*Electrical Conductivity.*—The resistance of pure nickel is stated to be 12,600 C.G.S. units. Professor Barrett, F.R.S., to whom the Author is specially indebted for the unvarying interest taken in his alloy work, has, during the last three years, in collaboration with Mr. W. Brown, B.Sc., Assistant Physicist in the Royal College of Science, Dublin, also been conducting an extensive research on the Electrical Conductivity and Magnetic Permeability of the Nickel-Iron alloys referred to in this Paper, also other alloys made by the Author. The results of Professor Barrett and Mr. Brown's investigations will shortly appear in the Transactions of the Royal Dublin Society. Meanwhile, by the courtesy of Professor Barrett, the Author has the pleasure of giving the results of these experiments as regards the nickel-iron alloys described in this Paper. As regards conductivity, these results are in part shown in Fig. 9, Plate 1, and bring out in a very clear manner the rapid rise in resistance produced by gradually increasing percentages of nickel. It is curious to find that this rise is quite inde-

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pendent of the hardness of the material. Usually the Author has found in iron alloys that increasing hardness indicates increasing resistance, but it is not so in the nickel-iron alloys. The material in the harder zone, 10 per cent. to 17 per cent. Ni, offers a considerable increase of resistance, but it is only when arriving at the much softer material containing above 19 per cent. of nickel that the highest resistance is reached. For example, the alloy containing about 30 per cent. of nickel is very soft, yet its resistance is exceedingly high—about four times that of the 1 per cent. to 2 per cent. nickel steel. The many curious anomalies met with in iron alloys are specially observable here, and it will be seen how greatly they add to the difficulty of a satisfactory explanation being offered.

Dr. Fleming, F.R.S., and Professor Dewar, F.R.S., carried out an interesting series of tests which were referred to in a joint Paper[1] by them on "The Electrical Resistance of Metals and Alloys at High Temperatures approaching the absolute Zero." Dr. Fleming also carried out some further experiments of much interest, described in his Paper[2] on "Electrical and Magnetic Research at Low Temperatures." In this he refers to a number of the Author's specimens, including several nickel-iron alloys, and shows some of the curious properties they possess.

Professor Barrett also found that samples D and E (1·92 and 3·82 per cent. Ni) compared very favourably, both as regards high susceptibility and high magnetization, with the best samples of pure iron now used for dynamo and transformer work; in fact, he considered them practically equal to pure iron of 99·75 per cent. Fe, or Swedish iron of similar purity.

*Thermal Treatment.*—Mr. F. Osmond, of Paris, to whom the Author has been much indebted from time to time in connection with the thermal experiments relating to his alloys, has carried out a valuable series of experiments for the Author to obtain the various heating and cooling curves from the alloys described in the Paper. The Author wishes to specially express his thanks for the valuable information this has added to the knowledge of these alloys. The heating and cooling curves will be found in Figs. 1 to 6, Plate 2.

Mr. Osmond stated that as he considered the series of alloys of iron and nickel presented to him by the Author was a very complete one, and as the nickel in it is practically the only

[1] Philosophical Magazine, vol. xxxiv. p. 326.
Proceedings of the Royal Institution, vol. xv. p. 239.

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variable element, it appeared to him it would be interesting to submit the series to different tests, though Dr. Hopkinson[1] and Mr. H. Le Chatelier[2] have already made known the same remarkable properties of some similar alloys.

Below is a list of the samples experimented upon, and their chemical composition, according to analyses given by the Author.

| Mark | C. | Si. | Mn. | Ni. |
|---|---|---|---|---|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| A | 0·19 | 0·31 | 0·79 | 0·27 |
| C | 0·13 | 0·23 | 0·72 | 0·95 |
| E | 0·19 | 0·20 | 0·65 | 3·82 |
| G | 0·17 | 0·28 | 0·68 | 7·65 |
| J | 0·23 | 0·24 | 0·93 | 15·48 |
| K | 0·19 | 0·27 | 0·93 | 19·64 |
| L | 0·16 | 0·30 | 1·00 | 24·51 |
| M | 0·14 | 0·38 | 0·86 | 29·07 |
| N | 0·16 | 0·31 | 1·08 | 49·65 |

*Tests by Cooling.—Points of Transformation.*—It is known that there are produced, during the cooling of carburetted iron, three evolutions of heat, which Mr. Osmond has named, to preserve the notation of Tchernoff, $A_1$, $A_2$, $A_3$. $A_1$ represents a combination of iron with carbon; $A_2$ and $A_3$ relate to the iron itself. In steel containing 0·16 per cent. of carbon, $A_3$ occurs at about 820°, $A_2$ between 750° to 700°, $A_1$ about 660°.

The samples A (0·27 per cent. Ni) and C (0·95 per cent. Ni), Figs. 1 to 6, Plate 2, gave the three same points, lowered to the respective temperatures of—

| | | | |
|---|---|---|---|
| A . . . . | 775° to 765° | 715° to 695° | 645° to 635° |
| C . . . . | 755° to 745° | 695° to 685° | 625° to 615° |

In the sample E (3·82 per cent. Ni), $A_3$ and $A_2$ are combined in one double point $A_{3-2}$ between 645° to 635°; $A_1$ is reduced or lowered to 565° to 550°.

In the sample G (7·65 Ni), the double point $A_{3-2}$ is lowered still further to 515° to 505°; $A_1$ disappears—that is, it unites itself to the preceding point, or perhaps the carbon, as Mr. Werth has discovered, takes, in alloys containing a large percentage of nickel, a distinct form resembling graphite.

As the percentage of nickel increases, the position of the point

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[1] ...edings of the Royal Society, vol. xlvii. p. 138.

[2] ...s Rendus, vol. cx. p. 283 (February 10th, 1890), and vol. cxi. ...ember 22nd, 1890).

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of disengagement of heat in the scale of temperature invariably continues to be reduced. It falls to 130° or 120° in sample J (15·48 per cent. Ni); to 85° to 65° in K (19·64 per cent. Ni); and the transformation is not altogether completed in L, at even ordinary temperatures (24·51 per cent. Ni). M (29·07 per cent. Ni) no longer shows any notable disengagement of heat. N (49·65 per cent. Ni) presents a disengagement which, by its position (380° to 340°) and its very feeble intensity, appears to correspond with that of the transformation already known as regards the metal nickel itself.

The samples, A to G inclusive, were left to cool in a porcelain tube loosely closed at the ends with stoppers of asbestos; the others were placed in the open air, cooling in the tube occurring too slowly at the critical and interesting point.

The quickness of the cooling and its initial temperature, the influence of which on hard steels and on alloys of iron with chrome and tungsten is great, only play here a secondary part, of a similar order to that of iron containing similar percentages of carbon, and this notwithstanding the large percentages of nickel present.

*Magnetic Properties.*—The appearance of magnetism during cooling coincides with point $A_2$. The alloys A to L (24·51 per cent. Ni) are strongly magnetic, with a decrease of magnetism from G (7·65 per cent. Ni), so far as can be judged by qualitative tests. M (29·07 per cent. Ni) is almost non-magnetic, and becomes notably more so at about − 70°, but only in a temporary manner; the magnetism reappears in N (49·65 per cent. Ni), probably owing to the excess of nickel. J (15·48 per cent. Ni), K (19·64 per cent. Ni) and L (24·51 per cent. Ni) are very freely polar-magnetic. The sample L resembles most the alloys studied by Dr. Hopkinson and Mr. H. Le Chatelier. This material becomes absolutely [1] non-magnetic if it is not allowed to cool under 50°; it again becomes magnetic between 50° and zero approximately, and only loses this new changed condition by re-heating to redness.

Mr. Osmond found that the M samples (29·07 per cent. Ni) possessed very peculiar properties. When placed against a powerful magnet, the bars hung down, that is, took a vertical position, but when cooled down to − 70° C. they were much more subject to magnetic influence and remained horizontal. The bars again fell down and assumed the vertical position, as the normal temperature was again reached.

[1] The Author does not entirely agree with this conclusion.

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*Mechanical Properties.*—The points of transformation coincide exactly with the profound modification made in the mechanical properties of the material, a modification which has already been pointed out by the two experimenters already named. It is only necessary to re-cool the test-pieces between the jaws of a vice coated with asbestos and to try the metal with a file, in order to discover, in the samples J, K and L, that the allotropic transformation is accompanied by a great increase in hardness. It is also to be remarked that the hardness corresponds to the magnetic polarity, as in tempered steels. The alloys which have undergone their regular transformations above 500° (dull red), and those which have not undergone the whole of them, are equally soft to the file, although the latter are magnetic and the former are not. Hardness and polarity appear to correspond with incomplete transformations.[1]

This concludes Mr. Osmond's report of his experiments on the Author's series of nickel-iron alloys. He has also contributed an excellent Paper on the microstructure of the Author's samples to the Comptes Rendus de l'Académie des Sciences, May 9th, 1898.

*The Welding of Nickel-Iron Alloys.*—The Author's experiments regarding the welding of nickel-iron alloys seem to prove that, at any rate by the ordinary methods, it is not possible to obtain satisfactory results—in fact, it is very doubtful whether any of these alloy steels can be made to give true welds. Yet statements are put forth in the most authoritative manner that there is no difficulty in this. It may be possible to make two pieces of steel stick together, but that is a very different result as compared with a weld such as can be obtained with ordinary mild steel, as the test machine would soon show.

In order to test this question, the Author carried out a series of welding tests, given in the Table on the following page, upon several of the specimens of forged nickel steel described, the bars being $\frac{5}{8}$ inch wide, $\frac{1}{4}$ inch thick, and 4 inches long. As will be seen, the only success met with was in the milder specimens, and it is doubtful whether the welds, even in these cases, were of a thoroughly satisfactory nature.

Interesting data are given by Mr. F. Fleitmann in "Stahl und Eisen," 1889, p. 9, "On the Nature of the Welding of Iron and Nickel." Whilst not dealing with welding in the ordinary sense of the term, Mr. Fleitmann mentions curious results obtained when plating iron with nickel, by pressure between rolls at a welding

[1] aboratory of Mr. Troost, at the Faculté des Sciences de Paris.

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WELDING TESTS ON NICKEL-IRON ALLOYS.

The bars were $\frac{5}{8}$ inch wide by $\frac{1}{4}$ inch thick.

| Mark. | Analysis. | | | Result. |
|---|---|---|---|---|
| | C. | Mn. | Ni. | |
| | Per cent. | Per cent. | Per cent. | |
| A | 0·19 | 0·79 | 0·27 | Adhered, but could be opened with a sate when cold. Not properly welded. |
| F | 0·18 | 0·65 | 5·81 | Adhered fairly well, not so well as "A"; could be opened with a sate when cold. Not properly welded. |
| I | 0·18 | 0·93 | 11·39 | Fell to pieces. Would not weld. |
| M | 0·14 | 0·86 | 29·07 | " " " " |

heat. There was clear evidence of not merely a welding action taking place, but of an actual chemical combination between the two metals. Further experiments showed that the thin nickel coating or plating referred to had taken up quite a large quantity of iron, and that there was probably molecular interpenetration of the two metals, and that this took place at a temperature between 500° and 600° below their melting-points. Mr. Fleitmann attributes this action to volatilization of the iron atoms, and further confirmed this by exposing loose sheets of iron and nickel laid loosely together to a red heat for a considerable period, when it was found that the iron distils over in quite a notable quantity to the nickel sheets, forming a surface-covering without any welding or even adhesion of the two metals taking place. The molecular mobility seemed confined to the iron atoms alone.

*Self-Hardening Tests.*—The results are given in the Table on the following page. It was not to be expected, seeing the low percentage of carbon in these specimens, that any of them would show the property of becoming hard by merely heating and cooling in the open air, as with that kind of steel known as "self-hardening."

*Corrosion.*—Exaggerated claims have been made that nickel steel does not corrode, with the result that much disappointment has been caused. Before it had been possible to spend the necessary time in testing the hasty conclusion arrived at, descriptions were published of the marvellous manner in which nickel steel behaved in this respect under the most severe tests. It seemed to be forgotten that the basis of nickel steel was iron, and that in the nature of things, unless an extraordinary transformation in molecular structure was obtained, and of which

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SELF-HARDENING TESTS OF NICKEL-IRON ALLOYS.

Each specimen, 3 inches long by 1¼ inch diameter, was heated to a sparkling welding heat (about 1,250° C.) and cooled quickly in air.

| Specimen. | Analysis. | | Result. |
|---|---|---|---|
| | C. | Ni. | |
| | Per cent. | Per cent. | |
| A | 0·19 | 0·27 | Would not scratch glass. Very soft, filed easily. Crystalline. Soft tearing fracture. |
| B | 0·14 | 0·51 | Would not scratch glass. Very soft, filed easily. Crystalline fracture. |
| C | 0·13 | 0·95 | Would not scratch glass. Filed easily. Rather finer crystalline than B. |
| D | 0·14 | 1·92 | Would not scratch glass. Very soft, filed easily. Crystalline fracture. |
| E | 0·19 | 3·82 | Would not scratch glass. Very soft, filed easily. Crystalline fracture. |
| F | 0·18 | 5·81 | Would not scratch glass. Slightly harder than E, but still filed easily. Crystalline fracture. |
| G | 0·17 | 7·65 | Would not scratch glass. Harder than F, but could still file easily. Fine crystalline fracture. |
| H | 0·16 | 9·51 | Would not scratch glass. Hard but could file. Very fine crystalline fracture. |
| I | 0·18 | 11·39 | Would not scratch glass. Hard, could just file. Crystalline. Rather dry fracture. |
| J | 0·23 | 15·48 | No test made. |
| K | 0·19 | 19·64 | Would not scratch glass. Could file, though rather hard. Rather dry fracture. |
| L | 0·16 | 24·51 | Would not scratch glass. Rather hard, but could file. Dry fracture. |
| M | 0·14 | 29·07 | Would not scratch glass. Soft, filed easily. Fibrous fracture. |

there was no proof, the behaviour of the basis, iron, whilst perhaps modified in the higher nickel percentages, would much resemble that of mild steel. As regards lower percentages of nickel, 3 per cent. to 5 per cent., the Author believes its behaviour differs but little from that of ordinary steel. In the very high percentages there is no doubt less liability to corrosion, but even that seems after a while to change, and deterioration sets in very rapidly; in other words, there comes a time when a sudden breakdown occurs, and this whatever may be the corrosive medium employed. The Table on the following page gives interesting particulars of the Author's tests, and it is hoped they may prove valuable, as in the same Table are added the results obtained with various other steels, and also metals of different kinds.

The German naval authorities some time ago made very careful trials with nickel steel for screw propellers, two small boats being fitted, in the one case with ordinary steel, in the other with nickel

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steel. The result was that, whilst nickel steel did show some superiority, the difference was not great, or sufficient to make nickel steel worth adopting.

The same experience has been met with in the use of nickel-steel resistance wire. In a short time corrosion occurred in equally as objectionable a manner as in ordinary iron and steel wire.

The Author's tests were carried out on strips about $\frac{1}{16}$ inch wide, $\frac{3}{16}$ inch thick, and $3\frac{1}{2}$ inches long. These were carefully weighed, then immersed for 21 days in sulphuric acid of 50 per cent. strength, re-weighed, and the loss noted. This test has been found to give a very fair indication of the resistance to corrosion by various steels and alloys. The following Table shows the results:—

| Specimen. | Analysis. | | Condition of Material. | Corrosion. | |
|---|---|---|---|---|---|
| | C. | Ni. | | Loss in Grams. | Loss Per cent. |
| | Percent. | Per cent. | | | |
| C | 0·13 | 0·95 | Forged | 2·003 | 3·23 |
| E | 0·19 | 3·82 | „ | 1·611 | 2·95 |
| G | 0·17 | 7·62 | „ | 1·581 | 2·77 |
| I | 0·18 | 11·39 | „ | 1·390 | 2·60 |
| M | 0·14 | 29·07 | „ | 0·759 | 1·34 |
| Ordinary steel analysis about | 0·40 | Mn 0·80 | „ | .. | 3·97 |
| Mild steel analysis about | 0·25 | .. | „ | .. | 2·09 |
| 1287 L | 0·16 | 24·51 | Cast | .. | 1·37 |
| Platinoid | .. | .. | .. | .. | 0·35 |
| Metallic chromium | .. | Cr 98·00 | .. | .. | 0·03 |
| Metallic manganese | .. | Mn 99·00 | .. | .. | 10·60 |
| Nickel | .. | Ni 98·50 | .. | .. | Very slight. |
| Iron | .. | Fe 99·80 | .. | .. | 4·52 |

The Author has recently received an interesting report from one of the leading electrical engineers in Chicago, Mr. Summers, confirming his own views regarding this important point of corrosion, from which the following is taken:—

"We were using nickel steel of high percentage for our rheostats, but have been compelled to withdraw it and substitute German silver, owing to the metal corroding badly in a short time and thus damaging the rheostats. I find this characteristic of most alloys containing a considerable portion of iron."

Without doubt this is an accurate and trustworthy conclusion. The conditions to which the material is subjected in rheostat work may be specially conducive to corrosion, and the Author agrees with Mr. Summers' conclusions.

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## Part II.—Nickel Steel and its Uses.

*General Considerations Regarding Nickel Steel and its Uses.*—This Paper would be incomplete without reference to the practical application of nickel steel, but to prevent confusion between the research and immediate practical work, the Author has thought it better to separate this portion from his nickel-iron alloy experiments given in Part I.

Referring first to the contributions of others on this subject, Mr. James Riley's Paper on "Alloys of nickel and steel," read before the Iron and Steel Institute in 1889, was of special interest and importance, as being the first practical contribution to knowledge on this subject. There have also been excellent Papers by Mr. Henry Wiggin, read before the same Institute in 1895, by Mr. W. Beardmore on "Nickel steel as an improved material for boiler-shell plates, forgings, and other purposes," read before the Institution of Naval Architects in 1897, and the very practical Paper by Mr. F. L. Sperry on "Nickel and nickel steel," read before the American Institute of Mining Engineers, in 1895. The latter is specially valuable, as in it there is given a useful set of experiments relating to the influence of different percentages of carbon upon two particular alloys in which the nickel remains fairly constant, viz., 2 per cent. and 4 per cent., the important element carbon varying from 0·16 per cent. to as high as 0·91 per cent.

Apart from its use in armour, it is difficult to obtain data as to other applications of nickel steel upon a large scale. The Pope Company, makers of the Columbia bicycle in America, are stated to prefer nickel-steel tubing, and that by its use they are able to lighten its section and yet obtain equal or greater strength and safety than from carbon-steel tubes of the mild temper now ordinarily used for this purpose. No doubt if material could be produced possessing a high ratio of elastic limit to breaking load, considerable advances could be made by bicycle makers, enabling either tubing of lighter section to be used or the production of a machine with greater rigidity.

*Special Applications of Nickel Steel.*—(*a*) Hydraulic cylinders. An interesting application of nickel steel on a large scale is that of a heavy cast-steel hydraulic cylinder made by Messrs. Beardmore, Glasgow, for their forging press. This weighed no less than 64 tons, and was stated to contain about 2 per cent. of nickel.

(*b*) Forgings. A special application by the Bethlehem Company, U.S.A., who have done so much to extend the use of

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nickel steel, has been its use for piston-rods. Great trouble was experienced in obtaining satisfactory piston-rods for their 125-ton hammer. If the carbon steel used was made soft, bending occurred, or if harder, breakage. A hollow nickel-steel piston-rod was forged about 38 feet in length and 17 inches in diameter, the following being its composition:—C 0·34, Si 0·13, S 0·04, P 0·03, Mn 0·67, Ni 3·12 per cent. The material possessed an elastic limit of 22 tons, and a tensile strength of 41 tons per square inch, elongation 21 per cent., and reduction of area 40 per cent. The design of the rod was entirely altered as compared with the carbon-steel piston-rod formerly used, so that, although it is stated that since the use of nickel steel there has been no breakage, this cannot be put down as wholly due to the use of nickel steel.

The Annual Report of the American Navy Department for the year 1897 contains a very practical communication on the relative values of nickel and carbon steel for heavy forging work. The Author considers it so interesting and important that he gives it in full as follows. The conclusions arrived at are worthy of special note:—

"The high requirements for certain forgings for battleships Nos. 7, 8 and 9, serve to show what high qualities manufacturers are now able to obtain from carbon steel without the use of any special alloy. Engine columns for battleship No. 7 have been made by the Midvale Steel Company, and like parts for battleship No. 8 by the Bethlehem Iron Company, under the same specifications, the former of high-carbon steel, the latter of nickel steel. These forgings were annealed in both cases, but not oil-tempered. The specifications permitted the use of special steel, and it was supposed that that would be necessary to obtain the qualities required. The physical qualities of the high-carbon steel, as shown by the prescribed tests, were somewhat better than those of nickel steel; but a cold bend test which was much severer than the one specified determined the fact that the nickel steel was much tougher, though the tensile tests had shown greater elongation and reduction of area in the case of the other steel. These interesting extra cold-bend specimens were tested and sent to the Bureau by request. The high qualities of the high-carbon steel were mainly obtained by skilled treatment in the annealing furnace, and they show how much depends upon the heat treatment of metal. This fact is emphasised by the repetitions of this treatment, which are frequently necessary to obtain the high qualities now required in steel forgings used in the Navy for certain purposes; also the high-grade steel boiler plates used in the Navy are frequently made to pass second tests by heat treatment.

"As further evidence of the capabilities of heat treatment in producing high-grade material, it may be added that one of the high-carbon engine columns above mentioned might have escaped rejection had the application of oil-tempering been permissible. These columns were too large in section to safely subject them to this form of heat treatment, not having been designed with axial holes.

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"In this connection it may be added to the credit of the columns made of nickel steel, that thus far reports show no rejections in their case, and that for this reason the nickel steel will doubtless prove in this instance cheaper than the high-carbon steel. To bore high-carbon columns in order to oil-temper them, and so secure their acceptance or reduce rejections, would, of course, make the difference in the cost very much more in favour of the nickel steel."

Mr. H. F. J. Porter, of the Bethlehem Iron Company, Bethlehem, Pa., U.S.A., states that nickel steel is specially well adapted for forgings of the highest quality.[1] The Paper is of such importance as to entitle it to very careful consideration, and the Author gives Mr. Porter's conclusions in full.

Although forgings can be made to fill a large variety of specifications, they can, in general, be divided into six classes as follows: (1) Mild steel, annealed; (2) medium hard steel, annealed; (3) medium hard steel, oil-tempered; (4) nickel-steel, annealed; (5) nickel-steel, oil-tempered, No. 1; (6) nickel-steel, oil-tempered, No. 2. Each of these classes is supposed to cover a series of grades of steel, varying in strength several thousand pounds. In selecting the materials for the forgings of an engine and in drawing up the specifications therefor, the premise should not be omitted that "all forgings shall be made of open-hearth steel," and that "they shall be carefully annealed after forging."

Large shafts and similar forgings, crank and cross-head pins, should be made of fluid-compressed steel, and should be hydraulic-forged, not hammered. Wherever practicable, an axial hole should be bored through shafts to insure absence of any internal defects. If forgings are oil-tempered, the hole can be made larger in diameter than if they are simply annealed, and where the hole is 7 inches in diameter and above, they can be hollow-forged on a mandrel. A hollow-forged oil-tempered forging insures the highest attainable qualities, and can be specially recommended where the maximum strength with the greatest lightness is desired.

Where it is important that the quality specified should be obtained in the more important parts, physical tests of the forgings as delivered should be demanded. For such tests prolongations should be left on the ends of forgings for the purpose of having test specimens cut from them after forgings and treatment have been complete. Such prolongations should receive no greater reduction than the forging at its largest part.

The following Table shows the average physical qualities that

[1] "Fatigue of Metal in Wrought Iron and Steel Forgings" (Journal of the Franklin Institute, April, 1898).

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should be obtained in forgings made of the several grades of steel mentioned, the test specimens being 2 inches long between measuring points, and ½ inch in diameter, and cut from full-sized prolongations of the forgings after treatment, the elastic limit being determined not by the drop of the beam, but by an electric micrometer.

| — | Tensile Strength. | Elastic Limit. | Extension Percentage. | Contraction Percentage. |
|---|---|---|---|---|
| *Carbon Steel.* | Lbs. | Lbs. | | |
| 1. Annealed . . . . . | 58,000 | 28,000 | 28 | 55 |
| 2. Annealed . . . . . | 80,000 | 37,000 | 23 | 45 |
| 3. Oil-tempered, with axial hole . | 80,000 | 45,000 | 25 | 50 |
| *Nickel Steel.* | | | | |
| 4. Annealed . . . . . | 80,000 | 45,000 | 23 | 45 |
| 5. Oil-tempered, with axial hole . | 80,000 | 50,000 | 25 | 50 |
| 6. „ „ „ | 90,000 | 60,000 | 22 | 50 |

Excellent illustrations are given in Mr. Porter's Paper of the nickel-steel conning-tower for the U.S. battleship "Brooklyn," weighing in the rough about 36 tons, of the nickel-steel propeller shaft used in the same battleship, its total length being about 40 feet, and having an outside diameter of 17⅛ inches, with an inside diameter of 11 inches.

Professor Merriman is quoted by Mr. Davenport in a Paper read before the Society of Naval Architects and Marine Engineers in 1893 as having arrived at the conclusion that an ordinary steel shaft, to be of the same strength as the above-mentioned nickel-steel shaft, would require to be 18·9 inches diameter, and weigh nearly 53 per cent. more.

The test-bars taken from the "Brooklyn" hollow-forged propeller-shaft, and in the oil-tempered condition, showed an elastic limit of 27 tons, and a tensile strength of 42 tons, elongation 25·55 per cent., reduction of area 60·58 per cent.

It would appear there is considerable room for improving the material of propeller-shafts, for as many as four large steamers were not long since disabled in this way in a week, and the annual record of fractures is startling in its magnitude. Is it possible that no stimulus can be found to make shipowners take measures to prevent the constantly-repeated failures of one of the vital organs of a ship? It has been pointed out that a steel propeller-shaft is not so good as an iron one.

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It is no secret that Americans have for some time been pushing the introduction of nickel steel for propeller-shafts and marine-engine forgings, and the two monster steamers of the North German Lloyd are known to be fitted with Krupp's nickel-steel shafting. Was the success of the magnificent run of the "Oregon" in the late war, when it steamed 15,000 miles in 59 days, in any way due to its shafting being of nickel steel? This steel has, without doubt, a higher elastic limit than carbon steel, or, in other words, whilst a high elastic limit can be obtained from carbon steel, this is only by a sacrifice of toughness and ductility as compared with nickel steel.

The Bethlehem Company are furnishing, for an engine of 8,000 HP. to be used by the Boston Elevated Railway Company, a nickel-steel shaft 27 feet in length, averaging 34 inches diameter, and weighing about 30 tons. The steel is to show 22 tons elastic limit, with 18 per cent. elongation on 10 inches.

Nickel steel for air-reservoirs is stated to be exceptionally safe. It is claimed that they will stand nearly twice the pressure of air before bursting as compared with ordinary steel; also they do not fly when bursting. Specimens tested showed an ultimate strength of about 72 tons per square inch and a reduction in area of 60 per cent.

*Material for Armour and its attack.*[1]—The applications of nickel steel can only briefly be referred to.[2] There appears to be little doubt that Messrs. Schneider and Company, Le Creusot, France, were the first to introduce nickel steel for armour-plates on a large and practical scale, but excellent as the results have been with this steel, in both the soft and hardened condition, it has evidently not been found to meet all conditions, as now the best armour-plates are not produced from nickel steel alone, but of different alloy combinations, for example, nickel-chromium steel.

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[1] Although much credit was due to the late Mr. Harvey, the recent improvements in the manufacture of armour-plates by Mr. F. Krupp, whether as regards treatment or composition of steel, have marked a great step forward. The former process, whilst often giving good results, was not certain, specially as regards thick plates, whilst the latter seems able to produce thick or thin plates of wonderfully high resisting quality.

[2] Excellent papers on the subject of armour have been written by Mr. C. E. Ellis, "Recent Experiments in Armour" (Institution of Naval Architects, March 15, 1894); "The Armour Plate Question," 1894, by Captain W. H. Jacques; "The Present Status of Face-Hardened Armour," by Captain W. T. Sampson, U.S.N. (read before the American Society of Naval Architects, December, 1894), and by Lieutenant A. A. Ackerman on "Face-Hardened Armour" (Proceedings of the United States Naval Institute, vol. xxi. No. 1).

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As regards soft steel armour-plates, not face-hardened, the use of nickel, owing to its toughening effect, has no doubt proved of great advantage. The fatal cracking often resulting with carbon steel is largely prevented. It has not yet been proved why nickel has this effect, and the Author is inclined to believe that the action of nickel specially in mild or low carbon steel, is one of indirect rather than direct nature; in other words, its presence, in some way not yet understood, acts upon the large mass of the main constituent—iron—present, and confers upon it toughness even superior to the best wrought iron.[1] At the same time, owing to the carbon present, even when low, as in mild steel, nickel also confers the greater stiffness of mild steel, as compared with the too plastic and yielding nature of wrought iron. If a nickel-steel armour-plate was produced containing only traces of or no carbon, it is very questionable whether it would offer any advantages as regards resistance over a similar carbonless steel. This point is mentioned as tending to prove that the action of nickel is, at any rate in its lower percentages, indirect rather than direct.

In face-hardened plates there are other considerations. As is well known, ordinary carbon steel, carburized by cementation and face-hardened, was at one time thought to be as advantageous as nickel steel similarly constituted. That such plates were of excellent quality is shown in Figs. 1, 2, and 3, Plate 3, representing a 6-inch Harveyed plate, which sustained the attack of three foreign projectiles, each fired with a velocity of 1,815 foot-seconds, and also one of the Hadfield armour-piercing projectiles, of the usual ogival form. It may be mentioned that the latter penetrated the plate to a greater depth than the foreign projectiles. It may also be interesting to mention that in a further round, with a Hadfield projectile of special design as regards the head, complete penetration was obtained, as shown at 5 in the same Figs., the projectile being broken, but all its fragments passing through the plate. Another notable point was that although the projectile only struck the plate with the same velocity as the preceding rounds, and was not capped in any way, it effected complete per-

[1] The metal nickel possesses this remarkable advantage as compared with iron, that though its yield point or elastic limit is slightly less, its tenacity is nearly 50 per cent. greater than that of iron, viz., 32 tons against 22 tons per square inch. This is clearly proved by the results and full data given on p. 8, Part I. In its cast condition and comparing it with Professor Arnold's results for pure iron in the cast condition, its tenacity is much lower, viz., 16 tons (Ni), as against 20 tons (Fe).



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foration. This was the first time, at any rate in England (July, 1894), that a steel plate with Harveyed face had been perforated, and seeing that it had previously defeated three of the foreign projectiles adopted as standards for testing, the results show that British makers are prepared to meet Government requirements if encouragement and opportunity, by experiment and otherwise, are granted to them. Judging from the large number of trials described in the U.S. Army and Navy Bureau reports, this latter is specially the case in America.

The cost of experimenting may be heavy, but in these days of rapid advance, progress cannot be obtained without this side of the work being borne in mind. Experiments, costly as they may be, often prove the means of great eventual saving to the nation.

No doubt nickel steel which has been cemented is very sensitive to heat and subsequent quenching treatment, and may enable the hardening of the face to be more readily effected, but probably its action, which is indirect, does not confer much greater resistance in face-hardened plates though it increases the toughness. Further experiments, too, have shown that the resistance of nickel steel is much improved by other combinations, such as the addition of chromium or other elements; in other words, the nickel is chiefly useful as a toughening agent, so that apparently nickel steel alone has not been found suitable for the purpose.

As regards the percentage of nickel found best for armour-plate purposes, this is usually from 2·50 per cent. to 3·25 per cent., the carbon being about 0·30 per cent. The latter element is increased in the face portion of the plates by carburization to a much higher percentage, viz., from 0·70 per cent. to 1·00 per cent.

It may be of interest to give the following results which illustrate the application of this steel to armour-piercing projectiles.

Figs. 4, 5 and 6, Plate 3, show the results obtained in April, 1898, from a steel projectile made by the Hadfield Steel Company, Limited, Sheffield. The projectile, 10 inches calibre, weighing 500 lbs., struck the steel plate ("all steel," not face-hardened) 15½ inches in thickness, with a velocity of 1,940 foot-seconds, and an energy of 13,103 foot-tons. The projectile pierced the plate, 8 feet of backing, and about 30 feet of earthwork. Being then found whole and uninjured this was considered to be a somewhat remarkable result. The plate, which was of remarkably good quality as regards toughness and showed no cracks after the round, is illustrated by Fig. 5, and the projectile after the tests by Fig. 6. The projectile under this severe test shortened only

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0·07 inch in length, and increased 0·02 inch in diameter. An instant displacement of metal had to take place equal to a cylinder 10 inches in diameter and 15½ inches in length, a somewhat unique bit of punching.

Another Hadfield projectile was fired in March, 1894, with a low velocity (1,690 foot-seconds) against a nickel-steel plate containing about 0·30 per cent. of carbon, and probably not less than 3 per cent. of nickel, proportions similar to those first adopted by Messrs. Schneider, and also afterwards adopted by the American makers, the Bethlehem Company, as well as those in England and on the Continent. The excellence of the Hadfield projectile and of the steel plate were shown by the results; neither suffered as regards cracks or fracture. The velocity in this case was not intended to give sufficient striking energy to effect complete perforation.

(*d*) *Gun Steel.*—There is no doubt that a steel of high elastic limit, combined with ductility, is of great importance for this purpose. Naturally the high and repeated stresses occurring in modern artillery seriously fatigue steel of comparatively low elastic limit. The addition of nickel enables a tougher steel to be used, and this, without the corresponding loss of elastic limit met with in milder carbon steel.

It is understood that the American Government has built an 8-inch nickel-steel (containing 3 per cent. nickel) breech-loading gun of 35 calibres in length, the requirements being that the metal in the tube should have a tensile strength of 38 tons, an elastic limit of 19 tons per square inch, with an elongation of 20 per cent. No report is yet available as to the results obtained.

It is also commonly believed that the quick-firing guns for the new French and German field artillery have been constructed of nickel steel.

(*e*) *Boiler-Plate Steel.*—It is difficult to obtain any precise and accurate information whether nickel steel has been used for this purpose. It does not appear to have been so in this country, though it was stated[1] that the United States Government had ordered 9 tons for this purpose, the specification calling for a tensile strength of about 36 tons, with an elongation of at least 25 per cent. on 8 inches.

At the Boiler Manufacturers' Convention, held in Philadelphia, 3rd August, 1897, a report was received from their Special

[1] *Engineering*, 31 May, 1895.



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Committee on Materials and Tests, in which it was stated that whilst claims had been set up for the use of various alloy steels, including nickel steel, in the construction of boilers, the committee thought, that whilst a fair trial should be given to any new applications, so far there was but little ground for claiming such suitability.

It is claimed that Messrs. Carnegie produced the first nickel steel in America at their Homestead Works, Pittsburgh, with a view to applying it to boiler-plate material; a 5-ton heat was made, and rolled into $\frac{3}{4}$-inch plates. Test specimens cut from these showed an elastic limit of 27 tons, with an ultimate tensile strength of 45 tons, an elongation of 15½ per cent., and a reduction of area at fracture of 29 per cent. This would hardly appear to be sufficiently ductile for the purpose. Some of these plates were to be submerged in sea-water, to ascertain whether there was less corrosion than in ordinary steel, but the Author cannot trace whether this was actually done.

Mr. G. W. Melville, head of the United States Bureau of Steam Engineering, states in his last report that whilst nickel steel for high grade boiler-shell plates has given satisfactory physical results, its surface is still not equal to that of the special high-grade carbon steel (oil-tempered and annealed) possessing an elastic limit of about 19 tons, a tensile strength of 34 tons, and an elongation of over 21 per cent.

Mr. J. E. Stead has recently discovered that the iron present in nickel steel may be oxidized on the surface without the nickel present being affected. He suggests this is probably the cause of the peculiarly hard scale met with in rolling and forging nickel steel.

(*f*) *Fire-box Stays.*—An interesting trial is now proceeding in America regarding the use of nickel steel for fire-box stays of locomotives.[1] The steel contained 0·14 per cent. of carbon, and 3·7 per cent. nickel. The tensile strength was 39 tons, with an elastic limit of 28 tons per square inch, an elongation of 19·20 per cent. on 8 inches, and a reduction in area of 54·8 per cent. Further important tests were made with stay-bolts having straight shanks turned down to $\frac{3}{8}$ inch. These were then subjected, in a special machine, to a constant tensile stress of 1,000 lbs., and at the same time to a vibrating stress, one end of the bolt being securely fixed, the other undergoing oscillations of $\frac{1}{8}$ inch amplitude, at the rate of 500 per minute. The first specimen withstood 292,420; the second,

[1] *Engineering*, 2 April, 1898.

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219,220; and the third, 362,220 before breaking. This is stated to be three times as much as any stay-bolt of iron previously tested. Whilst it is admitted that a hard material, if the amplitude of the vibrating stress is not too great, gives better results than a softer and more ductile one; it is also found that, whilst ultimate breakage is only a matter of time, the more ductile material appears to stand longest. Certain fire-box stays are no doubt overstrained, and invariably break in the end. It has been considered doubtful whether nickel steel will give results superior to the milder varieties of carbon steel; but until the matter has been further investigated general conclusions cannot be stated.

*General Consideration of the Effect of Nickel upon Iron, and the part played by Carbon in such Alloys.*—Mr. M. C. White, of the Bethlehem Iron and Steel Company, U.S.A., one of the earliest workers in this field of research, who has continued investigation for several years in connection with various special applications of nickel steel on a large practical scale, has made the following statement, in a communication to the Author, which is one of a specially valuable and concise character:—

The tensile strength and elastic limit of nickel-iron alloys and nickel steel rise with increasing proportions of nickel, reaching a maximum at about 20 per cent. Passing this they begin to fall, and elongation increases abnormally up to 30 per cent. The ratio of elastic limit to tensile strength increases with increasing nickel, at first slowly up to about 10 per cent., where it makes a sharp rise, and then continues gradually up to 20 per cent., after which the ratio falls away rapidly.

The hardening effect of quenching ceases at about 10 per cent., but is quite marked in the lower percentages.[1] In this case the effect is heightened by the manganese, but with 0·06 per cent. manganese it is still decided. Between 10 per cent. and 20 per cent. nickel, neither quenching nor annealing exerts any decided effect, the variations being not more than 1 per cent. or 2 per cent., practically within the limits of error of testing. Above 20 per cent. quenching produces a softening effect which is decided at 30 per cent. Perhaps it would be better to call it a weakening effect, as the tensile strength and elastic limit are much lowered, the elongation increased, but the cutting properties shown by turning in a lathe are not perceptibly changed.

These results refer to alloys of nickel and iron containing

[1] Journal of the Iron and Steel Institute, vol. ii., 1894, p. 457.

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carbon from 0·06 per cent. to 0·10 per cent., which practically can be considered carbonless alloys, as it is impracticable to make them lower. The manganese ranged between 0·06 per cent. and 0·10 per cent.

Nickel tends to check segregation, due, probably, to the fact that it raises the melting-point of the carbides or cementing material, and causes the whole mass to set more nearly together. This is evidenced by the finer grain of nickel-steel ingots.

Nickel does not prevent blow-holes, and great care is required in the manufacture to avoid them, as they are less amenable to welding than in other steel.

There are many difficulties to be overcome in the handling of nickel steel as commercially made, where the carbon ranges from 0·15 per cent. to 0·90 per cent., the manganese from 0·30 per cent. to 0·90 per cent., and the nickel from 3·0 per cent. to 30·0 per cent. It is very susceptible to changes of temperature when containing the usual amounts of carbon and manganese, requiring considerable care in heating and working to bring out its best qualities, which are certainly worth all the labour bestowed upon it.

The fact that nickel raises the elastic limit of steel is easily proved, but to give a reason for this effect, which can be definitely proved, would be difficult. The best explanation is that it strengthens the cementing material up to a certain point (20 per cent.), and holds in a more rigid matrix the iron crystals which in nickel-steel exist in smaller aggregations; beyond this the cementing material is not so much strengthened as it is toughened, which accounts for the abnormal increase in elongation.

Mr. White's remarks fully bear out the results of the various tests given in the Paper, but it must be remembered that both the above and the Author's opinion relate specially to carbonless, or practically so, alloys of iron and nickel.

The further importance of changes produced by additions of carbon to nickel-iron alloys is very great, but it is impossible in a Paper of this kind, dealing with one special subject, viz., the effect of nickel upon iron, as far as possible carbonless, to touch upon this aspect except very briefly. What part, therefore, does carbon play in nickel-iron alloys and nickel-steel? There is very little doubt that the hardening capacity of the material is increased in a similar, though to a much less, degree to that of chromium in carbon-chromium steel, but nickel at the same time increases the toughness, or, at any rate, the increasing

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percentages of carbon in the presence of nickel cause the same decrease in toughness as would ordinarily occur when no nickel is present. It is in this latter respect that nickel-steel, that is, a carbon nickel-iron alloy, probably differs from other iron alloy metals.

An American naval authority, Lieutenant Ackerman, in his Paper before-mentioned, considers that in nickel-steel the nickel present renders more sensitive and increases the hardening capacity of the carbon. He even goes so far as to say that the difference in the effect of cooling the plates in the air of a cold moist climate as that of Sheffield, England, and the dryer warm atmospheres of Pittsburgh or Bethlehem in the States, might cause the difficulty said to be found abroad in machining unhardened carburized nickel-steel. He states that American armour makers have been able in a great measure to avoid these difficulties.

Whether the action of nickel is direct or indirect has not yet been determined. The Author is inclined to believe that its influence in medium and high carbon steel is rather in the direction of causing a more intimate combination between carbon and iron, and that the use of nickel is to toughen the matrix of the iron. When it has become possible, with the aid of the chemist, to distinguish and understand the action of the various carbide combinations, the matter will be more clearly understood. At present, even with the aid of chemical and micro-structure research, little is known on this point.[1]

As regards the alloys dealt with in the Paper, the aim of the Author to keep down the carbon in the specimens under examination to a low limit, and thus avoid as much disturbance as possible by its presence, was successful, but even the small percentage present, averaging 17 per cent., has without doubt considerable influence, and one which would have been emphasized if it had been possible to obtain tensile-test bars subjected to water quenching at various temperatures. Table II, Appendix III, illustrates this very clearly in the bending-bar tests.

In ordinary commercial nickel-steel, carbon must necessarily be present, for, as will be seen from the various tests relating to those

[1] The combination of manganese, for example, is evidently quite different from that of nickel; it would hardly have been possible to obtain the separation of carbon referred to on p. 57. The presence of manganese is at once a bar to the successful completion of the annealing process in the manufacture of malleable cast iron; nickel does not have this action. The carbon present may become combined or dissociated quite irrespective of the nickel present.

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specimens containing lower percentage of nickel (A to C, 0·27 per cent. to 0·96 per cent. Ni), the results obtained do not differ greatly from ordinary steel containing similarly low percentages of carbon.

The Author's specimens being so low in carbon, they do not form the basis for a research as to the effect of this element upon nickel-iron alloys, but he considers its effect cannot be entirely avoided. The metal iron itself does not become steel until sufficient carbon is present to produce the effect usually associated with all but the mildest steel, namely, the readiness with which its hardness is increased when water-quenched from temperatures above 750° C. or 800° C. It is found, however, that when carbon is also present in nickel-steel it does not interfere in any way with the usual combination of carbon and iron. Whether a triple compound is formed is not certain. It is quite possible that a carbide of nickel is formed in the same manner as carbide of iron, and that this is the particular formation which offers the special characteristics met with in nickel-steel. It is almost certainly proved by Mr. J. E. Stead's valuable investigations that there is a double carbide of iron and manganese, and it is therefore probable that there is a carbide of iron or a double carbide of iron and nickel.

That nickel may be absorbed by, or combine with iron, is to be inferred from the presence of graphitic carbon, or graphitic temper carbon, in almost pure metallic nickel. The Author has found as much as 1½ per cent. When molten, probably this was combined with the nickel, as is the case with carbon in molten iron. Then, too, Mr. Moissan has obtained in his electric furnace experiments nickel alloys containing as much as 13 per cent. of carbon, as shown by the following analysis:—

| Ni. | Carbon. |
|---|---|
| | Per cent. |
| 86·00 | 13·47 |
| 87·00 | 11·90 |
| 94·00 | 6·19 |

It is remarkable to find carbon present in such high percentages.

The Author has also obtained curious results with carbon nickel alloys, and they may be of service to those dealing with nickel-steel high in carbon, as showing the great care required in the heat treatment of such steel. After annealing a specimen of steel containing 1·28 per cent. carbon, 0·74 per cent. nickel, other constituents being normal, the elastic limit was found to drop in

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an unaccountable manner from 32·00 tons to 12·50 tons per square inch, and the tensile strength from 64·00 tons to 21·00 tons per square inch, or little more than that of pure iron. Upon an

EFFECT OF ANNEALING UPON HIGH CARBON NICKEL STEEL.

| Specimen Mark. | Treatment. | Tons per square inch. | | Elongation on 2 inches. | Reduction in area. | Analysis. | | |
|---|---|---|---|---|---|---|---|---|
| | | Elastic Limit. | Breaking Load. | | | C. | Gr. | Ni. |
| | | | | Per cent. | | Per cent. | Per cent. | Per cent. |
| 2,196F | Unannealed | 32·00 | 64·00 | 2·50 | 3·04 | 1·28 | Nil | 0·74 |
| 2,197F | Annealed | 12·50 | 20·50 | 20·50 | 21·80 | 0·16 | 1·23 | 0·74 |

examination of the fractured test-bar, which is of very dark fibrous nature, the cause was clearly seen—namely, that practically the whole of this carbon present had been converted from the combined into the graphitic form.

It is doubtful whether, either in the presence of chromium, tungsten, or manganese, it would be possible to obtain such a conversion or precipitation of the carbon. Nickel, therefore, would appear to produce in this respect a result analogous to that of silicon and aluminium in cast iron—that is, to convert or precipitate the carbon from the combined into the graphitic form. This experiment is an important one, as it probably supports the Author's theory that the action of nickel in steel is indirect rather than direct. In manganese or chromium steel the carbon is apparently bound much too firmly to be disturbed. If, therefore, it is eventually found that the carbide of nickel in iron alloys does not exist, it would appear that the action of nickel is chiefly that of a toughening agent, or if a carbide exists, that it is one of a nature much more easily dissolved.

It is not probable that this action of nickel occurs in mild steel, in which it is doubtful whether there is any more risk of changes in the carbon condition such as above described than in ordinary steel. In the "hard zone," specially of the series of nickel-iron specimens described by the Author, the nickel *per se* produces a great "stiffening" effect, but it must be borne in mind that there is also present about 0·75 per cent. of manganese and 0·16 per cent. of carbon. The effect of either element in these percentages is not entirely negligible. If a nickel-iron alloy could be obtained containing neither of these elements, it is probable that the stiffness noticed would be considerably reduced.

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But what, then, is the effect of nickel upon iron in the presence of appreciable quantities of carbon, for example, 0·30 per cent. and upwards? Probably in the matrix alloy the iron and nickel are more intimately combined than other iron alloys, and whilst in the presence of carbon the nickel has a comparatively secondary effect, it enables the original matrix to maintain more of its toughness than ordinarily occurs in carbon-iron combinations.

The hardening effect proceeds in the ordinary manner noticed in carbon-iron alloys, but the matrix itself, being of a more intimate and tougher nature, a correspondingly better—that is, tougher—result is obtained with the carbide of iron combination in the presence of nickel.

Probably with the growing and increasing importance of microstructure research, those who have specialized this branch will before long be able to say if there are grounds for such a theory.

The well-known Russian metallurgist Chernoff has stated that steel is composed of crystals of metallic iron cemented by carbide of iron, the result being that in the case of nickel-iron alloys the inter-crystalline spaces (a subject which has been fully and carefully investigated by Mr. T. Andrews, F.R.S., as regards ordinary steel) are much more completely filled, and the cohesion consequently rendered more powerful. The points of solidification of the cement and crystals are nearer, thus producing or maintaining a more intimate interweaving of the elements. In support of this theory may be incidentally cited the fact that without doubt nickel-iron alloys show less tendency to segregation, which apparently shows that the combinations formed at high temperature are more intimately maintained when the alloy cools and becomes solidified than is the case with ordinary steel. Suggestions such as the foregoing must necessarily be modified according to the nature of the alloy under consideration.

As regards the alloys dealt with by the Author, and in which the carbon is low, this theory must to some extent be modified. As indicated in the preceding paragraphs, it is possible that the combination is probably not so much one of greater intimacy between the carbon and iron, as of the more intimate union of the nickel and iron irrespectively, or to some extent so, of the small percentage of carbon present. In the presence of carbon, or of higher percentages of carbon than in the alloys under consideration, action of a different nature may occur, and a double carbide of nickel and iron be produced.

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## Conclusion.

In gathering together the history of a particular metal, its origin, history, and application, the fact is strongly shown that discoveries and improvements are effected slowly and gradually—in fact, there is evolution equally in the metallurgical world as elsewhere; also that many minds must be concerned in the advancement of any branch of knowledge: it is very seldom that a discovery complete and perfect in itself springs from a single mind. There is more interdependence each decade, and no doubt fortunately so, as the whole world is brought nearer in touch, and interests of various kinds are found to be much in common. Happily to the man of science there is no nationality; race and confusion of tongues are to him but accidents of birth. That scientific evolution disregards nationalities is well illustrated in the case of the metal nickel and its developments. The Swedish chemist Cronstedt, at work in his laboratory, conceives the idea that the deceptive Kupfernickel is a metal containing a new element; from him it passes to other Swedish scientists, thence to those of German, French, and other nationalities. Attempts are made by Faraday to artificially produce meteoric iron; similar efforts are afterwards made in France, Germany, and elsewhere. Apparently a period of inactivity follows, but, all the time, first one and then another experimenter adds his facts to the general stock. The production of the metal itself is perfected. Garnier discovers in New Caledonia a source of future supply of ore for producing the metal. The discovery of the wonderful Sudbury mines, Canada, which lay idle for nearly a generation, is again brought to the front by the passage of the Canadian Pacific Railway through a hill composed of nickel ore. Many minds are set to work, method after method follows, until nickel can be obtained with something like uniformity, of satisfactory quality, and not too high in price.

Finally, as regards the metallurgy of nickel as applied to iron and steel, Marbeau, in France, applies the matter experimentally; Schneider, in France, perfects its application to a number of purposes, chiefly armour-plates; Riley brings the manufacture to a practical issue in England; American and Canadian enterprise follow in the perfecting of cheaper methods of producing nickel, and suddenly, so it appears to the world, a new product—nickel-steel—appears. But after all it is not so; it has taken about 125 years to arrive at the stage reached to-day. No one person, no one nationality, can lay claim to its discovery, to its inception.

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From a chart on genealogical lines, how much would be seen to have sprung from the laboratory experiments by Cronstedt. But, if it were possible, far beyond the work of the Swede would be discovered the early workers of the old world in China and Japan, about whose work dates and facts are inaccessible. Apparently, to modern ideas, mention of nickel appears to have struggled into existence between the years 1600 and 1700, but, as the Author has already pointed out, the metal must have been well known, not merely centuries, but almost thousands of years earlier.

The Paper is accompanied by diagrams and photographs, from which Plates 1–3 have been prepared.



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# APPENDIXES.

## APPENDIX I.

### Early History of Nickel; Compounds and Ores of Nickel.

*Origin of Name and Early History.*—The earliest references on record in the English language relating to nickel appear to be contained in a valuable work of reference on "The Elements of the Art of Assaying Metals," published in 1741, by Dr. J. A. Cramer (dedicated to the Honourable J. Winthrop, Esq., Fellow of the Royal Society, and printed for Thomas Woodward, at the Half Moon, between the Temple Gates). Extracts from the quaint preface to Dr. Cramer's book will be found in Appendix II.

In Mr. Fourcroy's valuable and interesting "Encyclopédie Méthodique," published in 1808, there is given a full account of what was known at that date regarding nickel. He states that in 1694 Hierne for the first time spoke of a certain mineral containing nickel, commonly known as Kupfer-nickel, or false copper. Henckel considered it to be a species of cobalt or arsenic mixed with copper. Cramer and Henckel made the same statements. This was commonly accepted until about the middle of the eighteenth century, when in 1750 Cronstedt recorded in the Mémoires de l'Académie de Stockholm that it was possible to extract from the mineral in question a new metal possessing quite different properties to any then known. He named it nickel, though his product was really a matte or mixture of nickel, arsenic, and cobalt. His results were challenged by a number of experimenters until Bergman took up the matter. After a most laborious series of investigations, the latter proved the correctness of Cronstedt's work in the month of July, 1775. An account of his research work was put before the University at Upsala by Mr. Arfvedson, one of Bergman's assistants. By this very exhaustive research it was proved that the metal obtained did not contain any copper, and that its properties were entirely novel. At that time so great was the current of scientific opinion that the so-called "nickel" was an alloy or impure metallic regulus of cobalt with arsenic, copper, and iron, this view being supported by such well-known chemists as Sage and Monnet, that in 1775 Bergman, assisted by Arfvedson, went to the trouble of producing a large number of alloys of iron and copper, of iron, copper and arsenic, and of iron, copper and cobalt, in order to prove that they would not give a product at all resembling nickel. A mass of experiments, the labour of carrying out which can hardly be appreciated to-day, eventually resulted in fully proving the strength of Bergman's claim that Cronstedt's impure metal, whilst in itself an alloy, was mainly composed of a new element—nickel.

Notwithstanding Bergman's work, it was not until some time later (about 1803) that Messrs. Proust, Thenard, and Richter, of Berlin, obtained the purified metal. Richter, to whom great credit was due, found the specific gravity of nickel to be 8·278, and 8·666 in the forged state, which are almost the same figures as now accepted.

A special tribute must be accorded to Richter's work, seeing its comparatively early date, a fact brought home by the style of the date of his Paper, "30ième Nivose, An 13" (30th December, 1804). This Paper was translated into French by Mr. F. A. Oetzel in the Annales de Chimie, vol. 53, p. 164, entitled "Nickel

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absolutely pure. Proofs that it is a noble metal. Its preparation and special properties," by Dr. J. B. Richter, Berlin; translated by F. A. Oetzel. Richter's examination of the metal which he had produced showed that (1) its colour was between that of silver and pure tin; (2) it was unaffected by the air or moisture, it does not rust; (3) it was particularly ductile, and could even be reduced cold into thin plates; (4) its tenacity was very considerable, and it could be reduced to 0·01 inch in thickness as well as drawn into wire; (5) its high melting-point was described; (6) it was found to possess very considerable magnetic qualities. Richter completes his description by saying, "Nickel not only belongs to the perfect metals, but to the noble metals." He somewhat quaintly concludes his dissertation by stating, "L'auteur prie ici, dans une note, tous les chimistes qui ont l'occasion d'employer un feu aussi fort et aussi long, de répeter ses expériences sur le nickel; il propose à ceux qui n'ont pas cette occasion, et qui désirent malgré cela de faire des expériences sur ce métal, de vendre de celui qu'il a fait, à 3 écus de Prusse (12 liv.) le gros. Il prévient qu'il ne pourroit donner à une personne qu'un gros et demi jusqu'à trois gros, à moins qu'on ne le destinât à faire des expériences; il pourroit alors en donner sept à huit gros. Dans tous les cas, il donneroit des baguettes, des plaques et de l'oxide fait avec le métal pur. Il demeure Wilhelmstrasse, No. 86, à Berlin."

Richter's wonderfully accurate work, which at that time, or nearly 100 years ago, must have been carried out under many difficulties, entitles him to great credit for his accurate research and description of the metal.

Its principal properties were also successively established by others, including Proust, Tupputti, Berthier, and many others. There do not appear to have been any early English workers in this particular field. The world, especially England, owes a debt of gratitude to that indefatigable band of early Swedish, German, and French workers, such as Vauquelin, the French discoverer of chromium in 1897; Scheele, the Swede who discovered manganese in 1771; Klaproth, who discovered uranium in 1789, and titanium in 1795; Cronstedt, the Swede, who discovered nickel in 1750; Von Reichembach, who discovered tellurium in 1782; D'Ehlinjahrt, who discovered tungsten in 1783; as well as Margraff, Glauber, Wartz, Gahn, Rinman, and others. How great was the work of this band of investigators, these searchers after truth! With the imperfect apparatus at their command, and what would seem now an almost entire absence of data or basis from which to make any start for research work, their difficulties must have been such as can hardly be realized.

It would appear that so far back as 1694 Hierne described the copper-coloured ore known as "Kupfer-nickel," a combination of nickel, arsenic, cobalt, and other elements, but from which no copper could be extracted. It was so named because he believed it to contain copper, but this designation was but one of derision, and indicated the miners' contemptuous opinion of the value of such ore, who knew well that the ordinary opinion of the day was wrong.

As to the exact significance of the term. "Old Nick's Copper" is suggested by Mr. A. G. Charleton,[1] the word "nickel" being itself probably derived from the low German "Nikker," which stands for the devil or hangman. Still more probable is the explanation that the German "Nix" or "Nixe," Anglo-Saxon "Nicor," was the name given to a kind of water goblin, and now specially reserved for the king of all goblins.

It is singular that one of the copper alloys now widely used in the arts, and

[1] "Nickel, its History, Use, and Distribution" (Journal of the Society of Arts, May 4th, 1893).

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into the composition of which nickel largely enters, should still retain a mark of its origin, viz., German silver.

The metal nickel may well be said to have been until comparatively lately one of a perplexing and apparently contradictory nature. It was therefore natural enough that Cronstedt should christen the element "nickel." He employed a portion of its then common nomenclature as a mineral, and hence the present designation, and unlike most of the other elements, the same whether in the English, German, or French language.

*Early Experiments as to the Practical Use of Nickel as an Alloy with Iron.*—Whilst science is indebted to Swedish and German scientists for the earliest work regarding the production of the metal nickel as well as other elements, as regards suggestions for the practical applications of nickel to alloy work, Englishmen can justly claim to have been first in the field, thanks to the master mind of our great scientist, Faraday. In 1820 and 1821 he and Stodart made a considerable number of iron and steel alloy experiments, amongst them being alloys of iron and nickel. Many of these experiments were carried out under his instructions at Sheffield, in the works of Mr. Charles Sanderson, though he does not appear to have personally visited that city. He melted together Swedish horseshoe-nail iron with 1 per cent., 3 per cent., 5 per cent., 10 per cent., 20 per cent., and 50 per cent. of nickel. The metals were found to combine well, the 3 per cent. alloy being specially malleable, and working satisfactorily under the hammer. It is somewhat singular that this should prove to be the same percentage as that usually adopted in the nickel-steel armour-plates of the present day. The specific gravity of this alloy was stated to be 7·7 in its cast state, and that of the 10 per cent., 7·849. The 10 per cent. mixture was not so malleable and more disposed to crack when being forged. All the specimens were strongly attracted by the magnet, a fact confirmed by the Author, and distinctly opposed to the statements of some recent experimentalists regarding the non-magnetic qualities of high nickel-iron alloys. No doubt in the presence of carbon such alloys may possess varying magnetic qualities.

Faraday probably took up this subject because his attention had been drawn to the numerous experiments of Bergman and Richter with nickel about the beginning of the 19th century, and also from the fact that he was aware that meteoric iron contained nickel. In an account of some of his experiments he particularly mentions that meteoric iron from the Arctic regions was found to contain 3 per cent. of nickel, while that from Siberia gave nearly 10 per cent.[1] He attempted to reproduce imitations of meteoric iron by alloying together horseshoe-nail iron and nickel in various proportions. Faraday, with his usual clear observation, pointed out that whilst his nickel alloys did show less signs of rusting than ordinary steel, this was not to the extent that had been expected. In this he was no doubt perfectly correct, notwithstanding that many absurd claims have recently been made that nickel steel is rustless. In any case, only the higher percentage alloys show any marked advantage as compared with ordinary steel, and even they cannot be compared with copper, for example. This has been already dealt with on p. 43 of Part I. Faraday's valuable experiments do not seem to have led to any commercial application in England, but they opened the way to this.

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[1] Faraday's Papers on the Alloys of Steel (Stodart and Faraday) were read on March 21st, 1822, and appear in the Philosophical Transactions of the Royal Society for that year (p. 253); also in the *Philosophical Magazine*, vol. lx. p. 363. An interesting report of his various experiments will also be found in his work entitled, "Experimental Researches in Chemistry and Physics" (1859).

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Berthier, in France, is reported to have also carried out at a little later date nickel-iron alloy experiments, but it is difficult to obtain definite statements as to what was done, whereas Faraday made and put on record quite a number of examinations of his alloys.[1]

Regarding other early experiments, Mr. R. Flechner mentions in a Paper on "Nickel Mining and Smelting,"[2] that Hofrath von Gersdorff, in 1824, applied nickel to industrial purposes; but even this was several years later than Faraday's experiments.

In a very carefully prepared and most interesting article by Professor Otto Vogel,[3] claim is made, and apparently with good grounds, that Mr. Wolf, a German manufacturer of Schweinfurt, was the first to utilize nickel steel commercially. An interesting confirmation of this is given by Dr. Justus von Liebig,[4] who states that Mr. Wolf combined nickel and iron in perfectly ductile alloys, which could be readily damascened.

Nickel steel is stated to have been at that time brought into the market, though no details are given as to its composition, under the name of "meteoric steel," this name naturally being adopted, because meteoric iron contained nickel. No proof is available that there was any demand for the material.

Fairbairn recorded some later experiments,[5] but no definite details appear to have been kept, except that the mixtures were made with No. 3 Blaenavon pig-iron, the effect of which was stated to cause a considerable diminution of strength, both as regards deflection and impact properties.

Dr. W. L. Austin[6] states that nickel iron appeared for the first time in large quantities at the New York Exhibition of 1853, Mr. Philip Thurber having produced it from nickeliferous limonite coming from Marquette. Little further, however, appears to have been done in a practical way until a much later date, or about 1870, when Mr. Alexander Parkes, of Birmingham, took out several patents for the production of alloys of iron and nickel. The Author had not been able to ascertain that the results he obtained were applied commercially to any large extent. The application of nickel to iron alloys appears to have then again slept for almost 20 years, this probably being due to the difficulty of obtaining a satisfactory nickel metal. Mr. Fleitmann, of the Iserlohn Works, Germany, made, therefore, a considerable step forward when he improved the metal itself by the addition of a small amount of magnesium, enabling soundness and malleability amongst other qualities to be obtained. Still later, Mr. Marbeau, of the Société Ferro-Nickel, Paris, perfected other improvements in the production of the metal, and much credit is due to this worker.

Further improvements followed, and in Mr. F. Gautier's interesting communication on Ferro-Metallic Alloys to the "Congrès International des Mines et de la Metallurgie," held in connection with the Paris Exhibition of 1889, it is stated that the first active manufacture of ferro-nickel as well as nickel steel was commenced in 1885, at Mr. Marbeau's works at Montataire, France, under the supervision of Mr. Bertheault. Similar results were obtained at the Imphy

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[1] *Quarterly Journal of Science*, vol. 6, pp. 324–369.

[2] Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1887, p. 63.

[3] Stahl und Eisen, 1895, 2, p. 718.

[4] Annalen der Pharmacie, 1832, vol. ii. p. 237.

[5] "Experiments to Determine the Strength of some Alloys of Nickel and Iron, similar in Composition to Meteoric Iron" (Manchester Philosophical Society, March, 1853).

[6] Berg- und Huettenmaennische Zeitung, 1894, p. 69.

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Works, in 1887. Mr. James Riley, before whom these various results were placed, then took up the investigations and furnished his now well-known and valuable Paper on "Alloys of Iron and Nickel," to the Iron and Steel Institute in 1889. This Paper caused special attention to be drawn to the material, for although it appears that Mr. J. F. Hall, of Sheffield, had been working in a similar direction, his results had not been publicly put on record. The greatest credit is due to Mr. Riley for the energy and care he bestowed upon this important subject. Without doubt, the more extended use of nickel steel would have been long delayed if it had not been for the results of his experiments and the world-wide publicity given to his communication. His experiments were chiefly on nickel steels, with comparatively high carbon contents, this element varying from 0·22 per cent. to 0·85 per cent., and averaging about 0·50 per cent. in the twelve specimens examined and reported upon. Owing to the powerful influence of carbon upon nickel-iron alloys, the Author has tried to reduce this element to as low percentages as possible, in order to ascertain the exact influence of gradually increasing amounts of nickel upon iron. In his specimens, the carbon averages only 0·17 per cent., and, with one exception, does not exceed 0·19 per cent. The nickel commences at 0·27 per cent., and rises to 49·65 per cent.

The late Sir Henry Bessemer gave an interesting account of early experiments he made with alloys of nickel and iron.[1]

*Effect of Nickel upon Wrought Iron.*—There appears to be no reference to this subject in past literature or researches with the exception of the late Mr. A. L. Holley's Paper, "The Strength of Wrought Iron."[2] A very exhaustive set of tests were made upon forty-two different qualities of wrought iron, of which a most careful examination was made, including more than 350 analyses, and

| C. | Si. | S. | P. | Mn. | Cu. | Co. | Ni. | Slag and Oxide of Iron. |
|---|---|---|---|---|---|---|---|---|
| 0·02 to 0·06 | 0·17 to 0·26 | 0·007 to 0·01 | 0·21 to 0·31 | Trace to 0·5 | 0·31 to 0·43 | 0·05 to 0·11 | 0·17 to 0·34 | 0·67 to 1·30 |

170 tensile tests, with equally numerous welding and other tests. Some of the specimens were reported to contain small percentages of nickel; the set of specimens "M" analysing as above.

Holley reported that the nickel present did not appear to affect the strength, but that this material stood high on the list in welding capacity.

Mr. G. H. Billings, of Norway Iron Works, Boston, Mass.,[3] states that his experiments with nickel gave red shortness; this seems to have been the trouble met with by most of the early experimentalists.

*Meteoric Iron.*—Through the existence of meteors there is direct proof of the presence of nickel outside. Sir Norman Lockyer, in his fascinating work on the "Chemistry of the Sun" (p. 77), published many years ago, says, "I consider I am entitled to conclude that nickel is visible in the solar atmosphere."

It may be interesting to mention that about 1794, the French Academy

[1] Journal of the Iron and Steel Institute, No. II., p. 191.

[2] Transactions of the American Institute of Mining Engineers, Vol. VI. p. 101.

[3] "The Properties of Iron alloyed with other Metals," Transactions of the American Institute of Mining Engineers, Vol. V. p. 447.



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decided by a majority of votes "that falls of meteor stones do not occur." Fortunately, however, the young scientist Chladni, of Wittenburg, upon whose communication the French Academy had passed the opinion just mentioned, did not present his theory to the Academy without most thorough researches, made principally upon the meteoric iron of Krasnojarsk which had been discovered by Pallas. The strong opposition and prejudice he had to face may be gathered from the fact that several eminent scientists of the time attacked him most violently, some even going so far as to number him "amongst those who deny all law and order in the universe, and who do not stop to consider that they are the cause of evil in the world."

There ought not to have been even then any doubt as to the fall of meteoric masses, as a remarkable one occurred at Agram in May, 1751, and fully established the existence of this curious phenomenon.[1]

Prejudice, however, could not permanently stand in the way of advancing knowledge, and very early in the present century further interest in this matter was shown by the fact that the chemical analysis of meteorites was taken in hand, principally by Howard in England, Klaproth in Germany, and Proust in France. Aloys von Widmannstätten, then manager of the Imperial Porcelain Manufactory at Vienna, also gained for himself much distinction by discovering those structural conditions, now named after him, which form such a characteristic feature of meteoric iron, though it must not be forgotten that, as named later, Vauquelin showed that not all meteoric iron contained nickel.

Boussingault and Mariano de Rivero found at Socavita (Eastern Cordilleras) a mass weighing 18 cwt., 7·3 to 7·6 specific gravity.

Large numbers of smaller deposits have been investigated, some showing material difficult to file, some malleable, and others not so. Five specimens analysed contained from 90 per cent. to 92 per cent. of iron, and 6 per cent. to 9 per cent. of nickel.

Mr. Mornay found in 1811, near Bahia in Brazil, a mass of meteoric iron, first observed in 1784, about 7 feet long, 4 feet high, and 2 feet thick. If this is correct it could not have weighed less than 7 tons. Mr. Wollaston analysed a fragment, which gave 4 per cent. nickel.

A fragment of another meteorite fall, found by Captain Barrow in South Africa, about 200 miles from the Cape of Good Hope, fell into the hands of Mr. Sowerby, who, it is stated, in 1820 converted it into a sword-blade about 30 inches long. He further stated that the blade acquired any desired temper, a remarkable degree of elasticity, and that it is now the property of the Emperor of Russia. Its analysis is reported to have been 10 per cent. nickel.[2] As a confirmation of Mr. Sowerby's statement, it may be mentioned that the Esquimaux in Greenland are reported to use knives made of aerolites found there.

There was recently brought to the United States Navy Yard, Brooklyn, a very unique meteorite weighing nearly 100 tons. This is the famous Greenland meteorite found by Lieutenant Peary in a voyage off Cape Sabine near Melville Bay. It is about 12 feet long, 4 feet thick, and 6 feet high. As may be imagined, no little difficulty was experienced in excavating this huge mass from its frozen bed off to the coast, a distance of about ¼ mile, and safely securing it on board the little vessel "Hope" to meet the rough weather of Arctic seas. Finally, the difficulties of navigating a vessel with such a mass of

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[1] "The Useful Metals and their Alloys" (Scoffern).

[2] Such an alloy would be very hard, and probably able, if containing a certain percentage of carbon, to retain an edge, though hardly one of good quality.

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iron on board were increased as it rendered the compass useless for navigating. A coast voyage all the way back had to be made, and the port of Sydney, in Nova Scotia, was touched when the "Hope" was burning her last ton of coal. The analysis of this meteorite showed that it contained about 92 per cent. of iron, and 8 per cent. of nickel.

Mr. Otto Vogel[1] gives a very full account of various researches on this subject, and Professor E. Cohen, of Greifswald University, has apparently almost exhausted the subject.[2] In the first part of this work the constituents of meteorites are fully dealt with. Professor Cohen believes that the element nickel is never absent from meteoric iron, its percentage varying up to as high as 20 per cent., but more than 11 per cent. is of rare occurrence. Vauquelin, however, says that he found some meteoric iron which did not contain nickel, but the analytical methods at his disposal were naturally not very perfect.

Although it is much more easy in these advanced times to distinguish and determine various natural products by the many facilities now available for chemical or physical examination, in earlier times it was not so easy to differentiate between terrestrian or natural iron of nickeliferous character and that of meteoric origin. The former variety undoubtedly exists, but Cohen states that its percentage of nickel is either considerably higher or lower than that of meteoric origin. Nordenskjöld discovered near Ovifak, on the Island of Diskö (Greenland), in 1870, "native or natural iron" containing from 0·5 per cent. to 3·0 per cent. nickel, some cobalt, 2·82 per cent. of phosphorus, and 3·69 per cent. of carbon.

The Table on pages 69 and 70 gives the percentages of nickel found in, and other particulars of, various meteorites which have been discovered. Meteoric iron usually possesses the great disadvantage of being red short, no doubt owing to the presence of sulphur, and this has caused it to be considered worthless. Comparatively pure specimens are, however, met with, as will be described shortly, and these are no doubt as malleable as similar artificially produced nickel-iron alloys.

Dr. Otto Buchner, in a work on meteorites, states that in 1802, during the construction of a road in the neighbourhood of Bitburg, north of Trèves, a large mass of iron, weighing more than 1,600 kilograms, was found buried a few feet below the surface of the ground. Soon after an attempt was made at the Pluwig Iron Works near Trèves, to melt this down, but whilst the iron appeared malleable in the cold state, after being re-melted, it was of no use in "balling," or forming a bloom. Analyses of this material by Strohmeyer (No. 1) and John (No. 2) gave:—

| —— | Fe. | Ni. | Co. | Mn. | Si. | S. |
|---|---|---|---|---|---|---|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| No. 1 . . . . | 81·8 | 11·9 | .. | 0·2 | .. | 5·10 |
| No. 2 . . . . | 78·82 | 8·1 | 3·00 | 4·0 | 0·8 | 4·50 |

Another instance occurred, in 1847, at Rittersgrün, in Saxony, where a peasant, tilling the ground, found a lump of iron weighing 80 kilograms, but no blacksmith could be found able to make use of this "old iron," as it was called.

[1] Stahl und Eisen, 1896, 2. pp. 412–48.

[2] "Petrography of the Universe" (E. Cohen, "Meteoritekunnde," 1894).



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| Place where Found. | Year. | Percentage of Nickel. | Percentage of Cobalt. | Hardness. | Ductility. |
|---|---|---|---|---|---|
| Elbogen . | 1420? | 8·517 | 0·762 | .. | .. |
| Tucuman . | 1783 | 10·0 | .. | .. | Very ductile, easy to hammer or file |
| Bahia (Bemdegó River) Brazil . | 1784 | 3·9 to 5·1 | ? | .. | Not very tough, rather inclining to brittleness |
| Zacatecas | 1792 | 9·7 to 9·8 | 0·44 to 0·66 | Soft | Tough, hard to break |
| Oaxaca (Mistecá) Mexico . | 1804 | 9·917 | 0·745 | .. | .. |
| Burlington | 1819 | 8·14 to 8·89 | ? | .. | .. |
| Bohumilitz (Bohemia) | 1829 | 3·81 to 8·12 | ? | .. | .. |
| Potosi . | 1839 | 6 to 11 | 0·53 to 0·7 | .. | Very tough |
| Sevier County | 1840 | 5·84 to 6·52 | 0·33 to 0·80 | Harder than ordinary wrought iron | Can be hammered |
| Babbs Mill | 1842 | 12·42 to 17·10 | 2 037 | .. | .. |
| Seeläsgen . | 1847 | 5·3 to 6·22 | 0·43 to 0·66 | Very soft | Malleable |
| Murfreesboro' . | 1849 | 2·4 | ? | Hard | Can be hammered |
| Tucson (Arizona) | 1850 | 3·07 | 0·42 | .. | .. |
| Tazewell . | 1853 | 14·62 to 15·02 | 0·43 to 0·50 | Hard | Very tough |
| Madoc. . | 1854 | 5·35 | .. | Very soft | Can be hammered |
| Union County . | 1854 | 3·32 | .. | .. | .. |
| Cohahuila. | 1855 | 3·18 | 0·35 | Easy to saw | Can be hammered |
| Oktibbeha | 1857 | 62·01 | 0·72 | Not hard | Exceedingly tough, cannot be sawed without much difficulty |
| Heidelberg | 1861 | 0·071 | | Hard, cannot be filed or sawed | Brittle |

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| Colour. | Lustre. | Fracture. | Solubility. | Specific Gravity. |
|---|---|---|---|---|
| .. | .. | A little coarse, dense | .. | .. |
| .. | .. | A little coarse, dense | .. | .. |
| White | Very bright | Granulated specular | .. | 7·816 |
| .. | .. | A little coarse, dense | .. | .. |
| Almost silver-white | .. | .. | .. | .. |
| White like German silver | .. | .. | .. | .. |
| White like ordinary bar-iron | .. | A little coarse, dense | .. | .. |
| .. | .. | .. | Does not rust in damp air | .. |
| Whiter than wrought iron | .. | .. | .. | .. |
| Very white | Very bright | Dense, fine-grained. | .. | .. |
| .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. |
| Like white pig-iron | .. | Very crystalline | .. | .. |
| Silver-white | Bright | Crystalline, retains its lustre on the fracture surface for a long time | .. | .. |
| .. | .. | .. | .. | .. |
| When polished almost silver-white | .. | .. | .. | .. |
| .. | .. | .. | .. | .. |
| Silver-white | .. | Distinctly crystalline | Not soluble in acids | .. |
| Iron-grey | Bright | Granulated | Readily soluble in $HNO_3$ and dilute $H_2SO_4$ | .. |

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Whilst in the preceding case sulphur was the injurious element, here phosphorus was probably the disturbing impurity. An analyses showed :—

| Fe. | Ni. | Co. | P. |
|---|---|---|---|
| Per Cent. 87·13 | Per Cent. 9·63 | Per Cent. 0·58 | Per Cent. 1·37 |

Further instances of meteoric iron containing much sulphur and phosphorus are as follows:—

SULPHUR PRESENT.

| — | Ni. | S. |
|---|---|---|
| | Per Cent. | Per Cent. |
| Iron of Tazewell, Claiborne County, Tennessee, U.S.A. . . . . | 24·708 | 4·000 |
| ,, ,, ,, ,, ,, | 12·665 | 2·395 |
| ,, Rokycan (Bohemia) . . . . . | 8·840 | 1·030 |
| ,, Xiquipilco (Mexico) . . . . . | 7·290 | 0·860 |
| ,, Zacatecas ,, . . . . . | 9·895 | 0·845 |
| ,, Bohumilitz (Bohemia) . . . . . | 4·010 | 0·810 |
| ,, Xiquipilco (Mexico) . . . . . | 9·800 | 0·790 |

PHOSPHORUS PRESENT.

| — | Ni. | P. |
|---|---|---|
| | Per Cent. | Per Cent. |
| Iron of Xiquipilco (Mexico) . . . . . | 8·860 | 0·860 |
| ,, Xiquipilco ,, . . . . . | 8·900 | 0·780 |
| ,, Heidelberg . . . . . | 0·071 | 1·229 |

Meteoric iron has a specific gravity varying between 6·5 and 8·1, chiefly about 7·6 to 7·9, pure iron being 7·88, and pure nickel 8·8. As regards its hardness, the reports are very conflicting, but it is probable that no meteoric iron has been found which could not be filed; it may therefore be described as being comparatively soft. Various reports are also given as to its welding property, but it is doubtful whether any nickel-iron alloy can be successfully welded, or, at any rate, when the percentage exceeds 50 per cent., and certainly not such a peculiar mixture or alloy as that of which meteorites are usually composed.

In view of the peculiar behaviour of certain high-nickel steel alloys as regards magnetic qualities, this point has been dealt with in Part I (pages 32 to 34), but, owing to the special interest of the subject, a brief reference may be made to the magnetic qualities of meteoric iron. Although it is doubtful whether absolutely carbonless nickel-iron alloys are non-magnetic, no matter what the thermal treatment to which they have been subjected, yet ordinary nickel-steel alloys containing from about 24 per cent. to 30 per cent. behave very curiously, varying in magnetic and non-magnetic character according to the heat treatment. The Author considers this largely, if not entirely, depends upon the particular percentage of carbon present. If less than about 0·25 per cent. of carbon is present it is doubtful whether the changes stated to have been noted by several investigators occur, or at any rate, they do not occur in the natural condition of the

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alloys. Professors Cohen and Leick examined a large number of meteoric iron specimens as to their magnetic susceptibility. Of fifty-seven specimens, all were magnetic; forty-one, seemed more or less strongly permanently magnetic, the coercive force proving fairly strong. Three specimens remained permanently magnetized to only a very low degree, and seven did not retain any, behaving similarly to soft iron. Cohen considers that the varying characteristics of meteoric iron may be owing to the great heat to which they have been subjected either in their original formation, or by the heat engendered in their passage through the atmosphere. Seeing that the late Dr. J. Hopkinson rendered certain artificial iron alloys, which are stated to have been previously non-magnetizable, magnetic by cooling below zero, Cohen made similar experiments with regard to meteoric iron, but found that after refrigeration, they exhibited the same nature as before, namely, that of soft iron. He therefore made a number of check-tests upon artificial nickel-iron alloys, with the following results:—

| No. | Percentage of Nickel. | At Ordinary Temperature. | After Heating. |
|---|---|---|---|
| 1 | 7 | Strong permanent magnetism . | Permanent magnetism. |
| 2 | 12 | ,, ,, ,, . . | ,, ,, |
| 3 | 25 | ,, ,, ,, . . | No magnetism. |
| 4 | 25 | ,, ,, ,, . . | ,, |
| 5 | 30 | ,, ,, ,, . . | ,, |
| 6 | 30 | Very faint ,, ,, . . | Not tested. |
| 7 | 35 | Faint ,, ,, . . | Faint magnetism. |

He concludes that, generally, the strength of permanent magnetism decreases in an inverse ratio to the percentage of nickel. No. 1 exhibited strong coercive force, Nos. 2 and 3 lost their magnetism after four weeks. As regards susceptibility to temporary magnetism, no change could be observed after strong heating. The Author considers that these experiments represent much more correctly the magnetic properties of nickel-iron alloys than those which have been usually put forward.

In view of the statements that nickel steel will not rust, all of which at any rate as regards percentages under 5 per cent. or 6 per cent., are probably inaccurate, it is of special interest to observe how meteoric nickel-iron alloys have behaved. Whilst a skin of rust offers considerable protection, it is found that nearly all meteoric specimens are easily attacked by atmospheric influence, this varying according to the percentage of nickel present; but below the percentages above mentioned very little protection is offered, and, in any case, they are subject to rapid corrosion.

In an interesting Paper by Mr. W. E. Hidden,[1] a very pure meteorite is described. Its analysis gave: iron, 85·33 per cent.; nickel, 13·34 per cent.; cobalt, 0·87 per cent.; phosphorus, 0·16 per cent. = 99·70 per cent., with traces of sulphur and carbon. This meteorite was exhibited at New Orleans in 1884–85, forming part of the South Carolina State exhibit.

The Berlin University Museum is very rich in its collection of meteoric specimens, and the Vienna Natural History Museum possesses one weighing about

[1] "On a Meteoric Iron from South Carolina," the School of Mines Quarterly, vol. viii. p. 31.

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1,033 kilograms. The British Museum also possesses, amongst other specimens, a block weighing 3,731 kilograms, which was obtained from Cranbourne in Australia. It is stated that the largest specimen in the world is kept in the Rio de Janeiro Museum, where it was brought some time ago from Bemfica, Bahia, at an expense of nearly £2,000.[1]

Meteorites have lately offered still further interesting fields for research, owing to the recent discovery in some of them of products resembling and in the actual form of diamonds. It has long been known that many meteorites contain graphite, but the meteoric iron from the Cañon Diablo (Arizona), in America, was the first examined which gave transparent diamonds, and all three varieties of carbon have been found in the meteorite. Mr. Foote, of Philadelphia, investigated this matter very fully, and Mr. Moissan has carried out further investigations on a very extensive scale. His work is described in a Paper read before the Paris Academy of Science in October, 1895. Professor C. Friedel, before the same society in December, 1892, showed that very careful analyses had proved beyond doubt that the diamond existed in the Arizona meteorite in small grains or fine powder disseminated through the iron. Mr. Foote was one of the first to describe the diamond formation of carbon in meteoric iron.[2] His interest was first aroused in the matter through having been asked to investigate a curious specimen of supposed meteoric iron, which had been found near the Cañon Diablo in Arizona, with the object of working the deposits for iron manufacture. The specimen presented to him was stated by the miner or prospector to be taken from a vein of pure meteoric iron, 40 yards wide in places, and distinctly traceable for 2 miles. Mr. Foote paid a visit to the locality, and although, finding that the deposit was not pure iron, and that the quantity and extent of the peculiar deposits had been greatly exaggerated, he met with several remarkable mineralogical and geological features. Nearly all the fragments of the peculiar specimens were found about 10 miles south-east of the Cañon Diablo, near the base of an almost circular elevation known locally as the "Crater Mountain." Although Mr. Foote states that a careful search failed to reveal lava obsidian or other volcanic products, the various surroundings of the deposits are a confirmation of Sir Robert Ball's belief, referred to later, that meteoric specimens may be of volcanic origin and nature, that is, produced by terrestrial volcanoes early in the Earth's history. Mr. Foote states that the "Crater Mountain" rises 432 feet above the surrounding plain, its centre being occupied by a cavity nearly $\frac{3}{4}$ mile in diameter, the sides of which are so steep that animals which have descended into it have been unable to escape, and have left their bleached bones at the bottom. The bottom seemed to be between 50 feet and 100 feet below the surrounding plain, the rocks which form the rim of the "crater" being sandstones and limestones, and are uplifted on all sides at an almost uniform angle of between 35° and 40°. About 2 miles from the base of the supposed "crater," two large masses of the deposits were discovered within about 80 feet of each other. The area over which the smaller deposits were scattered was about $\frac{1}{3}$ mile in length, and 120 feet wide. The largest weighed 201 lbs., and had a somewhat flattened rectangular shape, showing extraordinary deep and large pits, three of which pass entirely through the iron. Another mass, weighing about 40 lbs., was found broken in pieces, and it was

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[1] "Natural Nickel Iron," *Iron*, vol. xxxvii. p. 470.

[2] "A New Locality for Meteoric Iron with a Preliminary Notice of the Discovery of Diamonds in the Iron," American Journal of Science, vol. xlii. p. 413.

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in cutting one of these that the small diamonds, whose presence there has proved of so much scientific interest, were discovered. Besides these masses of considerable size, a careful search made by Mr. Foote, with the assistance of five men, resulted in the discovery of one hundred and eight smaller and larger masses, varying from a few ounces to 632 lbs. each. A thorough examination of many miles of the plain, however, proved that the "car-loads of iron," discovered by the prospector existed only in imagination.

Prof. G. A. Koenig, of Philadelphia, made a careful examination of these various specimens, and found them very hard, one section taking a day and a half to prepare, and a number of chisels being destroyed in the process. Afterwards, when attempting to polish the surface so as to bring out the characteristic Widmannstätten figures, it was found that the emery-wheel used had been spoiled. On examination, Prof. Koenig then found that the exposed cavities contained diamonds which cut through polished corundum. They were only small, and black, but mineralogically of great interest, as it is only comparatively recently that their presence in meteorites has been even suspected, two Russian mineralogists in 1887 first discovering traces of diamonds in a meteoric mixture of olivine and bronzite. Granules of amorphous carbon were also found in the cavity, and a small quantity of this treated with acid revealed a minute white diamond about $\frac{1}{50}$ inch in diameter. The proportion of nickel present was about 3 per cent.

Prof. Koenig sums up his chemical examination as follows:—(1) Diamonds, black and white, characterized by hardness and indifference to chemical agents. (2) Carbon in the form of a pulverulent iron carbide occurring in the same cavity with the diamonds. The precise nature of this carbide, whether containing hydrogen and nitrogen, is not ascertained except in so far that after extracting all iron by nitro-hydrochloric acid, the black residue passes into solution with deep brown colour upon treating it with potassium or sodium hydrate. From this solution acids do not give a precipitate. (3) Sulphur is not contained in the tough malleable portion of the meteorite, but in the pulverulent portion. (4) Phosphorus is contained in the latter, and not in the former. (5) Nickel and Cobalt, in the proportion of 2 : 1, are contained in both parts nearly equally. (6) Silicon is only present in the pulverulent portion. (7) The Widmannstätten figures are not regular. (8) The Iron is associated with a black hydroxide containing Fe, Ni, Co, P, in the ratio of the metallic part, and therefore presumably derived by a process of oxidation and hydration of the latter.

Although no exact analyses are given of the specimens, Prof. Koenig states that neither sulphur nor phosphorus are contained in this portion of the meteor.

These results relate to the discovery, for the first time, of diamonds in meteoric iron; Haidinger, in 1846, had discovered cubic crystals of graphitic carbon in the Arva meteoric iron. Much more recently, in 1887, Fletcher described somewhat similar crystals from the Yundagin, Western Australia, iron, both these having been regarded as pseudomorphs. Although in the previous remarks it has been assumed that meteorites originate outside the earth, it would appear that their actual origin is even now not at all clear. Sir Robert Ball[1] reviews the subject at considerable length. As against the hitherto ordinarily accepted theory that meteorites originated outside terrestrial influence, he states that it is a noticeable circumstance that the great meteoric showers (which undoubtedly did so originate) seem never yet to have projected a missile

[1] "The Story of the Heavens."

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which has reached the earth's surface. It may be mentioned that one of the earliest recorded showers of meteorites is that described by Livy, as having fallen about the year 654 B.C., on the Alban Mount, near Rome. Sir Robert Ball points out that stony meteorites fall much more frequently than the nickel-iron meteorites. He rejects as improbable the theory that meteorites are ejected from volcanoes on bodies outside the earth. Finally, after pointing out that meteorites have probably a volcanic origin, he makes the startling statement that the body upon which they originated has probably been the earth itself, and that it is more than likely that the meteorites met with on the earth were projected in the dim distant past, when terrestrial volcanoes were not so feeble as now. Consequently these missiles, by some mighty throes, were hurled forth with the adequate velocity that took them outside the gravitation of the earth. They would then be seized by the sun's gravitation, and compelled to revolve around the sun, but at each revolution they would traverse the point from which they were originally launched, viz., the earth. When this is the case, to use Sir Robert Ball's words, "the long travel of the little body is at an end, and it tumbles back to Mother Earth from which it parted so many ages ago." Sir Robert Ball cites, in support of his views, the Rowton siderite which fell at 3.40 P.M., 20th April, 1896 (weight about 8 lbs.). This was exhibited publicly at a bazaar in Wolverhampton, and afterwards presented by the Duke of Cleveland, upon whose property it fell, to the National History Museum at South Kensington. This siderite is of special interest to metallurgists, as it consists almost entirely of nickel and iron, a proof Sir Robert Ball considers that the origin is terrestrial.

Still stronger support of Sir Robert Ball's views is Nordenskjöld's meteor in Greenland, called the Ovifak meteorite. Close examination shows that this meteorite lies in a bed of basalt, which has been vomited from the interior of the earth. Sir Robert Ball further says that even those who believe in the meteoric origin of this specimen must be constrained to admit that shortly after the eruption of the basalt, and while it was still soft, this stupendous meteoric of gigantic mass and bulk happened to fall into this particular soft bed.

That this subject of the formation and origin of meteorites is not unimportant, may be gathered from the fact that Lord Kelvin has stated that one of the probable theories as to the world's formation is that it was built up of meteorites, and consequently it is quite possible that the metal nickel enters largely into the composition of the stupendous mass of material known as our world.

Professors Hartley and Ramage[1] record a number of investigations regarding the composition of meteoric iron. They state that the nickel is found as a principal constituent in all meteorites, meteoric iron, and siderolites, but that cobalt occurs in the two latter varieties only. Also that the chief points of difference between telluric and meteoric iron is the absence of nickel and cobalt in any considerable portion from the former, and the presence of manganese, while meteoric iron contains nickel and cobalt as notable constituents, and, except in minute traces, manganese is absent. The Paper is accompanied by some very carefully prepared plates, reproducing the flame spectra of six meteoric irons and three siderolites. The meteoric irons examined were from Virginia, U.S.A.; Arva, Hungary; Toluca, Mexico; Cañon Diablo, Arizona; and Thunda, Queensland. The siderolites were from specimens obtained in Atucama and Imilac, Chili; also Estherville, Iowa.

An interesting and authentic account of a probably unique meteoric appear-

[1] "Spectrographic Analysis of Iron Meteorites, Siderolites, and Meteoric Stones," Royal Dublin Society, May 19th, 1897.

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ance, though unfortunately no data of its actual composition were obtained, is the Great Australian meteor of the 7th May, 1895, described by Mr. H. C. Russell, B.A., C.M.G., F.R.S.[1]

Professor J. H. Vogt states[2] that of the more uncommon metals nickel and cobalt are present in the greatest quantity in the basic eruptive rocks. It would appear that Professor Vogt's conclusions strongly confirm those of Sir Robert Ball that the so-called meteoric deposits are of terrestrial origin.

It may be interesting to state that in an address to the Sheffield Literary and Philosophical Society, February 2nd, 1897, describing his fifty years' scientific investigations, Dr. H. C. Sorby, F.R.S., mentioned that it was his discoveries in the micro-structure examination of meteorites which led him to a similar examination of the micro-structure of iron and steel. For over twenty years these results attracted little attention, but from this pioneer work sprang the methods now affording such important practical aid to metallurgists, and now being so ably followed up by Arnold, Stead, Sauveur, Osmond, Martens, and others.

*Compounds of Nickel, also Ores.*[3]—Nickel ores and compounds are very numerous, more than sixty are known of the nickel-copper ore bodies. The following pages are chiefly devoted to the consideration of the natural combinations rather than those met with in the laboratory, except in so far as they concern practical applications from a metallurgist's point of view.

*Protoxide* (NiO), density 6·66 and non-magnetic.

*Sesquioxide* ($Ni_2O_3$) heated in a current of pure hydrogen becomes at about 190° a magnetic oxide, and by a further increase of temperature, protoxide, and finally at 230° metallic nickel.

*Sulphides of Nickel.*—There are many of these.

Subsulphide ($Ni_2S$) obtained by reducing in hydrogen the sulphate at a red heat. Upon calcining the sulphide in the presence of sulphur and in a current of hydrogen the same product is obtained, which is magnetic. There are also sulphides corresponding to the formula $Ni_2S_4$, anhydrous sulphide (NiS), hydrated sulphide ($NiSH_2O$).

*Fluoride of Nickel* ($NiFl_2$).

*Chloride of Nickel* ($NiCl_2$).

*Bromide of Nickel* ($NiBr_2$).

*Iodide of Nickel* ($Ni_2$).

*Arsenide of Nickel* ($Ni_2As_2$), which is Speiss in its crystalline condition, also as $Ni_2As_2$ and $NiAs_4$.

*Carbide of Nickel.*—Nickel heated in the electric furnace with carbon dissolves in the liquid state a certain amount of this metalloid, giving it up again in the form of graphite upon cooling. It does not produce a definite carbide, furnishing only a kind of cast-iron.

*Sulphide of Nickel* ($So_4Ni$).

*Arseniate of Nickel.*

*Carbonate of Nickel* ($Co_3Ni$).

*Cyanide of Nickel* (NiCAz).

*Nickel-Carbonyl* ($Ni(CO_4)$.—This can be prepared as follows:—Reduce oxide of nickel in hydrogen at about 400°. Then substitute a current of carbonic

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[1] Royal Society of New South Wales, July 3rd, 1895 (vol. xxix. 1895).

[2] "The Formation of Eruptive Ore Deposits," *Mineral Industry*, 1895.

[3] A large amount of general information on the metal will be found in Moissan and Ouvrard's excellent work "Le Nickel."

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oxide, allowing the product to "revenir" at a temperature of 30° to 40°. The carbonic oxide at once becomes charged with nickel carbonyl, which is collected by means of a U tube surrounded with refrigerating mixture, or by passing the gas through a suitable liquid such as petroleum, &c., which dissolves the carbonyl. The liquid obtained is colourless, boils at 46°, and soldifies at 25°. If the solution is heated in carbide of hydrogen it is decomposed, leaving upon the walls of the vessel holding it a brilliant deposit of metallic nickel.

*Acetate of Nickel* ($C_2H_3O_2$) 2Ni + $4H_2O$).

*Oxulate of Nickel* ($C_2O_4Ni$ +$22H_2O$).

*Tartrate of Nickel* ($C_4H_4O_4Ni$).

*Citrate of Nickel* ( ($C_6H_5O_7$) $2Ni_2$ + $14H_2O$).

Azary (1879), Anderson Stuart (1882), Schulz, Riche, and Laborde (1888), and others, have made very exhaustive researches as to the effects of salts of nickel upon the human system, and Mr. Riche, after a very careful examination, has

| Designation. | Fundamental Composition. | Colour. | Percentage of Nickel. | Country. |
|---|---|---|---|---|
| Nickeline . . } Kupfer-nickel . } | NiAs | Copperish red | 44·0 | Saxony. |
| Cloanthite . . } Rammelsbergite . . . } | $NiAs_2$ | Metallic white | 28·0 | ,, |
| Annabergite . } Nickel-ochre . } | $Ni_3As_2O_8$, $8H_2O$ | Greenish | 29·6 | ,, |
| Gersdorffite . } Nickelglanz . } Grey nickel ore } | NiSAs | Steely grey | 31·8 | Styria. |
| Millerite . . | NiS | Milk yellow | 61·8 | United States. |
| Siegenite . . } Linnéite . . } | (Ni, Co)$3S_4$ | Steely grey | 22·0 | Prussia. |
| Pentlandite . } Nickel pyrites . } | 2FeS, NiS | Bronze | 18·3 | Norway. |
| Grünauite . . } Nickel-bismuth } | Sulphide of nickel and bismuth | Steely grey | 40·0 | ,, |
| Breithauptite . } Nickel-antimony. . . } | NiSb | Copperish red | 32·6 | Hartz. |
| Ullmannite . } Nickelspeiss . } | NiSSb | Steely grey | 26·1 | ,, |
| Genthite . . } Rewdanskite . } | $Ro(Sio_2)2H_2O$ | Apple green | 12·6 | Ural. |
| Bunsenite . . | NiO | ,, ,, | ,, | ,, |
| Nicomélane . | $Ni_3O_2$ | ,, ,, | ,, | ,, |
| Texasite . . | $CO_3 3NiO, 5H_2O$ | Emerald green | 51·0 | Texas. |
| Morenosite . } Pyromélane . } | $SO_4Ni$ + $7H_2O$ | Clear green | 21·0 | Hesse. |
| Pimelite . . } Comarite . . } | Variable silicates of aluminium | Green | 15 to 20 | Saxony. |
| White nickel pyrites . } | ,, | Greyish white | ,, | Styria. |
| Red pyrites . | ,, | ,, ,, | ,, | ,, |
| Garnierite . . | (MgO,NiO) $SiO_2nH_2O$ | Green | 14 to 25 | New Caledonia. |

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concluded that nickel may be considered as harmless. Nickel has been found, according to Henry, in the mineral waters of Nayrac.

The nickel ores and formations may be divided into three main groups.

I.—Arsenical and arsenio-sulphide ores and corresponding combinations with antimony and sulphide, also bismuth and sulphur.

The principal varieties are:—

1. Arsenical nickel or the so-called "Kupfer-nickel"; red nickel pyrites or nickeline.
2. White nickel pyrites.
3. Nickel-glance or arsenical nickel pyrites.
4. Antimonial nickel-glance or pyrites.
5. Antimonial nickel, nickeliferous antimony.

II.—Sulphuret ores (without arsenic), more especially nickeliferous magnetic iron pyrites, millerite, &c.

III.—Silicate ores.

In the preceding Table Mr. Capelle (Bulletin de la Société Industrielle de Rouen, 1888) has given a full list of the various ores as now classified.

The more important nickel minerals are stated by Moissan to be the following:—

*Oxides.—Bunsenite.*—Discovered by Bergman in Saxony; hardness 5·5; density, 6·4; brown powder containing 78 per cent. nickel.

*Nicomelane*, or black nickel, is very rare, and is generally considered to be an impure sesquioxide of impure nickel.

*Sulphides.—Millerite.*—NiS; hardness, 3 to 3·5; density, 5·4: it usually contains a little iron, copper, and cobalt, and 64 per cent. of nickel.

Three other forms of the sulphides were discovered by Mr. Emmens in the Sudbury mines, Canada, in 1892.[1]

*Folgerite* (so named after the then chief of the American Navy Bureau, and who largely assisted in the development of nickel steel armour-plates).—Formula, NiS, FeS; hardness, 3·5. In the mass it is non-magnetic, but it is not so in small grains. Analysis: nickel, 31 per cent.; iron, 31 per cent.; sulphur, 37 per cent.

*Blueite* (named after one of the chief Canadian mining Commissioners).—This has a formula of $NiS_2 12FeS_2$; hardness, 3 to 5; density, 4·2; not magnetic. Analysis: nickel, 3·70 per cent.; iron, 41·00 per cent.; sulphur, 55 per cent.

*Whartonite* (named after Mr. Wharton, of Philadelphia). A double sulphide, having a formula of $NiS_2 7FeS_2$; hardness, 4; density 3·73. Analysis: nickel, 5·79 per cent.; iron, 45·98 per cent.; sulphur, 48·20 per cent.

*Grunauite or Saynite.*

*Jyepoorite or Carrollite.*

*Pentlandite or Nicopyrite.*—A sulphide of iron and nickel 2FeS, NiS, usually found with chalcopyrite at Lillehammer in Norway; hardness 3·5; density 4·6. Analysis: nickel, 22 per cent.; iron, 44 per cent.; sulphur, 30·00 per cent.; sulphate of magnesia, 3·2 per cent.

Most of the foregoing are comparatively rare, some very rare. The following are more abundant, but often contain but little nickel:—

*Pyrrhotites.*—These are very variable, but approach the composition of $Fe_7S_8$, and contain about 5 per cent. nickel. They are found at Varallo in Piedmont, Dillemburg in the Duchy of Nassau, in Sweden, in Scotland, and at the Gap Mine, Pennsylvania.

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[1] Mr. S. L. Penfield (American Journal of Science, vol. xlv. p. 493) thinks, however, that these specimens can be recognised as distinct species.

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The following list gives the analyses of these pyrrhotites:—

| Composition. | Cevia (Piedmont). | Sellabarca (Piedmont). | Sugmyra (Sweden). |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Nickel | 1·20 | 1·44 | 0·80 |
| Cobalt | 1·00 | 0·36 | Traces. |
| Copper | 0·50 | 0·72 | 1·00 |
| Iron | 20·00 | 20·00 | 7·00 |
| Sulphur | 28·00 | 28·00 | 11·00 |
| Gangue | 50·00 | 50·00 | 80·00 |
| Totals | 100·70 | 100·52 | 99·80 |

The Canadian sulphide will be dealt with more fully when considering those found at Sudbury.

*Sulphates.—Morenosite or Pyromelane.*—It has a formula corresponding to the following:—$NiSO_4 + 7H_2O$; usually comes from the oxidation of the sulphide. It is found at Cape Ortegal in Spain, also at Reichelsdorf (Hesse). Density 2·0.

*Telluride.—Melonite*, found at Calaverasco (California).

*Arsenides.—Red Nickeline or Kupfer-nickel.*—Also termed nicolite, is the mineral from which Cronstedt isolated the metal; it also contains traces of cobalt, iron, antimony, and sulphur, and is represented by the formula NiAs; hardness 5; density 7·5; found at Freiberg, Annaberg, Schneeberg in Saxony, Reichelsdorf, Andreasberg. In France, at Challanches in the Isère.

The following list gives the analysis of the mineral which, until the discovery of the new Caledonian mines, furnished almost exclusively the source from which the metal was prepared:—

| Composition. | Reichelsdorf. | Ayer. | Schladming. | Valais. |
|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. |
| Nickel | 44·2 | 43·5 | 30·6 | 20·3 |
| Cobalt | 44·2 | 0·3 | 2·2 | 4·0 |
| Iron | 0·3 | 0·5 | 8·9 | 12·2 |
| Arsenic | 54·7 | 54·0 | 51·0 | 55.7 |
| Sulphur | 0·4 | 2·2 | 4·2 | 1·8 |
| Gangue | 0·4 | 0·2 | 4·2 | 6·2 |
| Totals. | 99·6 | 100·7 | 96·9 | 100·2 |

*Chloanthite*, also called rammelsbergite, or white nickeline. Formula, $NiAs_2$; hardness 5·7; density 6·4; contains small quantities of copper, bismuth, and sulphur, and of the following analysis:—

| Composition. | Schneeberg. | Reichelsdorf. | Schladming. |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Nickel. | 28·14 | 20·74 | 13·4 |
| Cobalt | 28·14 | 3·37 | 5·0 |
| Copper | 0·50 | 3·37 | 5·0 |
| Arsenic | 71·30 | 72·64 | 60·5 |
| Iron | 71·30 | 3·25 | 13·3 |
| Sulphur | 0·14 | 3·25 | 5·4 |
| Bismuth | 2·19 | 3·25 | 5·4 |
| Totals | 102·27 | 100·00 | 97·6 |

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*Sulphoarsenides.—Nickelglanz, Disomose, Gersdorffite.*—This mineral, called grey nickel, is an arseno sulphide, having the formula $NiS_2 + NiAs_2$. The following Table gives the analysis of it; hardness 5; density 6·1; found in the Hartz and in Styria.

| Composition. | Loos (Sweden). | Harzgerode (Hartz). | Kamsdorf (Thuringia). | Schladming (Styria). |
|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. |
| Nickel | 29·94 | 30·30 | 27·00 | 38·42 |
| Cobalt | 0·92 | 30·30 | 27·00 | 38·42 |
| Iron | 4·11 | 6·00 | 11·00 | 2·09 |
| Arsenic | 45·37 | 44·87 | 48·00 | 42·52 |
| Antimony | 45·37 | traces | 48·00 | 42·52 |
| Sulphur | 19·34 | 18·83 | 14·00 | 14·22 |
| Quartz | 0·34 | 18·83 | 14·00 | 1·87 |

*Antimonide.—Breithauptite.*—NiSb; hardness 5; density 7·5.

*Sulpho-Antimonide.—Ullmannite.*—Often called nickelstibine; hardness 5; density 6·3; found in the Hartz; composition formula, $NiSb + NiS_2$. The following is its analysis:—

| Composition. | Freusberg. | Siegen. |
|---|---|---|
| | Per cent. | Per cent. |
| Nickel | 25·25 | 26·10 |
| Sulphur | 15·25 | 16·40 |
| Arsenic | 11·75 | 9·94 |
| Antimony | 45·75 | 47·56 |
| Totals | 100·00 | 100·00 |

In several varieties, and in particular as regards the corynite of Zepharowitch, a portion of the antimony is replaced by arsenic. The following is the composition of specimens of arseno antimonide found at Balen in the Pyrenees: nickel, 33 per cent.; iron, 1·4 per cent.; arsenic, 33·00 per cent.; antimony, 27·8 per cent.; sulphur, 2·8 per cent.

*Arseniates.—Annabergite or Nickel Ore.*—Found at Annaberg in Saxony; contains 38 per cent. to 48 per cent. nickel with arsenic.

*Carbonates.—Texasite.*—Often known as the emerald nickel, having a hardness of 3; density 2·6, with the following analysis:—

| Composition. | Texas. | Pennsylvania. |
|---|---|---|
| | Per cent. | Per cent. |
| Oxide of nickel | 58·81 | 56·82 |
| Magnesia | 58·81 | 1·62 |
| Carbonic acid | 11·69 | 11·62 |
| Water | 29·69 | 29·87 |
| Totals | 100·19 | 99·94 |

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*Silicates.*—This is a very important group of nickel minerals.

*Garnierite*, which will be described when dealing with the deposit of New Caledonia Company, being a silicate.

*Genthite or Nickeliferous Gummite.*—Important deposits have been found at Petrow in the Ural Mountains and in the Rewdin, from which we get the name Rewdanskite. These deposits were being commenced when the discovery of the superior ores of New Caledonia occurred. The analysis of the usual mineral is as follows:—

| Composition. | Soft Minerals. | Hard Minerals. |
|---|---|---|
| | Per cent. | Per cent. |
| Sand . . . . . | 20·08 | 29·30 |
| Silicon . . . . . | 26·48 | 24·93 |
| Aluminium . . . . | 1·41 | 2·23 |
| Oxide of iron . . . | 3·52 | 7·69 |
| Oxide of nickel . . . | 22·55 | 11·03 |
| Chalk . . . . . | 4·25 | 4·02 |
| Magnesia . . . . . | 3·36 | 8·83 |
| Loss in calcination . . | 14·80 | 13·25 |

There exists both in Spain and in Sardinia, a nickel mineral analogous to Garnierite.

To the foregoing list of ores must be added a magnetic pyrite and the nickeliferous chalcopyrite found in Spain, Scotland, and Piedmont.

| Composition. | Piedmont. | Sweden. | Scotland. | Canada. |
|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. |
| Nickel . . . . . | 1·2 | 0·5 | 7·1 | 3·1 |
| Copper . . . . . | 0·5 | 0·6 | 7·1 | 12·6 |
| Iron . . . . . | 20·0 | 23·0 | 50·0 | 29·2 |
| Sulphur . . . . . | 28·0 | 31·0 | 37·1 | 26·7 |
| Gangue . . . . . | 50·0 | 45·0 | 4·5 | 29·3 |

Finally, to complete the series, it should be mentioned that a source of nickel is found in the residue after the cobalt has been reduced, known as Cobalt Speiss, and the composition of which must necessarily vary, but having the following average analysis: nickel, 48·20 per cent.; cobalt, 1·63 per cent.; bismuth, 2·44 per cent.; iron, 0·44 per cent.; copper, 1·94 per cent.; arsenic, 42·08 per cent.; sulphur, 3·07 per cent.

*Nickel Ores and their Mining.—Norway.*—Nickel ores have proved to be much more abundant than expected a few years ago, but it is probably to Norway that is owed the first commercial working of the ore. Even in 1848 definite mining operations were carried on, and in 1876 it is stated that an ore production of over 40,000 tons was reached. Since then, owing to the richer mines discovered elsewhere, the output has been largely reduced. It is somewhat difficult to ascertain the exact condition of the nickel industry in Norway, but

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the Ringerike Nickel Works, which probably possess the largest nickel deposits in that country, both mine and smelt their ores, and were doing so in 1893. The Evse Nickel Works, which is stated to be worked by an English company, produced in 1893 about 2,000 tons of ore. Professor Vogt states that the Norwegian are of lower grade than the Canadian ores, and that the cost of production at the Ringerike Mine averages about 7*d.* per kilogram of nickel in the ore. Professor Vogt considers that metal assaying 98 per cent. to 99·5 per cent. Ni can be produced in Norway at 1*s.* 8*d.* per kilogram.

*England.*—Nickel ore has also been raised in Cornwall, at the St. Austell Consols, Pengelly, and Fowey Consols Mines, these having been worked in 1852 and onwards.

*Tasmania.*—Nickel ore is stated to have been recently found in Tasmania, and is reported as being specially pure, the silica and other foreign matter not exceeding 5 per cent. It averages from 8 per cent. to 10 per cent. nickel, and 5 per cent. to 6 per cent. copper.

*New Caledonia.*—The first great competitor to Norway was, however, the New Caledonian mines discovered by Mr. Jules Garnier, whose pioneer work is referred to elsewhere. It appears that D'Entrecasteaux in 1790 visited New Caledonia, and in his description of it says: "The inhabitants are not acquainted with the use of the bow, but are armed with darts, slings, and clubs. Besides fish, which is their principal food, they eat a kind of large spider. The land being in general barren, to appease hunger they eat a sort of greenish soft steatite." The greenish mineral product was no doubt the clay as now found there, which is rich in nickel. These deposits, discovered in 1864 and described in 1867, have proved to be of great importance. One of our large English Corporations, the London and Globe Company, is largely interested in their development. In the early days of its discovery a shipment of the New Caledonian ore was made to Sydney, N.S.W., with a view to determining the value of the "green coloured" ore for its copper contents! The results were, of course, the same as those obtained more than a century ago by the German miners who had the same idea as regards their product until it was found, to their chagrin, that the ore was but "Kupfernickel," or false copper. Fortunately the "false copper" is now a product which the world is very glad to get.[1]

Messrs. Moissan and Ouvrard, in their work "Le Nickel," state that the New Caledonia deposits are as follows:—

1. Kanala-Meri-Kuana.
2. Thio-Port-Bouquet.
3. Bourindi.

The first has been abandoned. Thio alone is being worked; it is a rich deposit, and situated about 50 miles nearer to Nouméa than Kanala. The third, which is the richest of all, is nearer to Nouméa, being about 120 miles from the sea. It has not yet been worked, and is held in reserve. There is considerable difficulty in transportation to the coast; this has to be done in boxes or cases containing about 25 kilograms, which are transhipped nearly a dozen times before arriving at the port for shipment to Europe. There was a great storm in the spring of 1894, which seriously damaged the buildings and other works of

[1] Two excellent and comparatively recent Papers have appeared on the New Caledonian ores, the first by Mr. David Levat, formerly Director of Le Nickel Company, "On the Geology and Metallurgy of the New Caledonian Nickel Ores" (Annales de Mines, vol. i. p. 141, 1892); and the second by Mr. Joseph Garland, "On Nickel Mining in New Caledonia" (Proceedings of the Institute of Mining and Metallurgy, 1894, p. 121).



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the Société de Nickel in New Caledonia, and the output was for a time seriously diminished.

The mining of the ore has been taken up chiefly by the Société Le Nickel and the Société d'Exploration of Paris, who have practically a monopoly of these deposits.[1] From official statistics published at Nouméa, the capital of the island, it appears that in 1892 the production had reached over 65,000 tons of ore per annum, and an area of 120,000 acres was being worked. The mines are found almost invariably in elevated positions, often at a height of from 2,000 to 3,000 feet, but with the drawback of a tropical climate in which to work them. Mr. A. G. Charleton believes that the nickel serpentine there met with is derived from the decomposition of peridote rocks, which were generally admitted to be of igneous origin, and he thought a satisfactory explanation of the deposit at the high elevations previously referred to would be found in the fact that the original rock masses from which the nickeliferous serpentine was derived were no doubt the latest and deep-seated volcanic overflows which might be expected to occur at high altitudes. The southern portion of the island consists of serpentines and schists, the former being the most prominent formation. In New Caledonia the nickel exists solely in the serpentine rock, and the ores occur in irregular veins, and chiefly in the fissures and joints of the rock, ramifying in every direction, and forming a skinwork or network of small veins. Sometimes they extend hundreds of feet, and to a moderate depth, partaking of some of the characteristics of a regular lode. Mr. Garland says that it is an established fact that there is a certain small proportion of the metal itself, nickel, in the serpentine rock, namely, from 0·25 per cent. to 0·75 per cent.—a somewhat curious fact.

There are various shades of colour in the ores, but the term Garnierite very well includes all—that is, the green silicate of nickel and magnesia. Its specific gravity is about 2·5, it varies greatly in hardness, sometimes being soft and brittle enough to crumble between the fingers, and in other cases hard enough to be cut into shape and take a fair polish. The darker the green colour, generally the richer the ore; in fact, the very pale green tint contains only a trace of nickel, and is of no value. Analyses of the ore vary very considerably, but the following may be taken as an average, omitting the water and minor constituents.

NiO . 19·73 $SiO_2$ . 44·75 MgO . 15·25

Mr. Arthur C. Claudet has also analysed another variety of the ore known as chocolate nickel ore.

| | Per Cent. | Ni. |
|---|---|---|
| NiO | 12·25 | (9·64 per cent.) |
| FeO | 32·20 | |
| MgO | 3·07 | |
| $Al_2O_3$ | 3·62 | |
| $SiO_2$ | 34·80 | |
| Water at 100° C. | 6·43 | |
| „ above 100° C. | 7·07 | |
| | 99·44 | |

Specific gravity 3·00.

[1] The New Caledonia ores are stated to be shipped to, and smelted into matte at works near Glasgow. The capital engaged in the French and Canadian Companies is said to be about £500,000 each.

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A peculiarity of the New Caledonian ores is the fact that cobalt is not found associated with nickel, as is often the case. The average quality of the ore shipped to Europe contains 7 per cent. to 8 per cent. metallic nickel, an ore of less than 6 per cent. not being considered saleable.

The cost of mining and preparing the ore for shipment is very variable, from 6s. to 40s. per ton, convict labour being chiefly employed. The ore costs roughly, put on board, about 40s. per ton. Mr. Garland says the natives, Kanakas, whose wants are few, seldom work in the mines, holding strong views as to the folly of work and the stupidity of the white man who is addicted to it.

Mr. Thomas Rickard has pointed out one important point in favour of the New Caledonian ores, namely, that the silicate ores there obtained contain no sulphur, as well as being free from copper and arsenic, whilst those from Sudbury are sulphurous, occurring as sulphides in nickeliferous pyrrhotites. Mr. Garnier's early difficulties arose from the fact that fuels containing sulphur were added when smelting the ores, and the presence of this element in the matte or ferro-nickel afterwards obtained was fatal to its use.

The French engineer, Mr. Jules Garnier, has done so much work in developing this metal, that his efforts must be specially recognised. It appears that from 1863 to 1867 he was exploring New Caledonia as a geologist, and during the course of his work found in the south-east and east of the island masses of green-coloured rocks. Suspecting the presence of nickel, he sent home specimens to his collaborateurs, Messrs. Janettaz and Terreil, at the Paris School of Mines, who at once informed him that he had discovered a new variety of nickel ore. Professor Dana, the well-known American mineralogist, who had also received specimens, in the 5th edition of his work on mineralogy (1875) published a description of it, and called it "Garnierite."[1] Mr. Garnier was then led to continue his investigations, especially as at that time Belgium had decided to adopt nickel coinage, and the price of nickel rose to the high figure of 45 francs per kilogram (it is now about 2 francs per kilogram). He therefore experimented with the New Caledonian ore, which upon fusion, owing to the ferruginous nature of its composition, gave him an alloy of nickel and iron certainly imperfect and impure, but whose physical qualities showed that when perfected it would offer great advantages. In his French patent, dated the 15th February, 1876, perhaps the first publication where it was thoroughly recognised that the value of such alloys would be very great, Mr. Garnier stated:—

1st. That it was necessary to first produce a "ferro-nickel" pig or cast-iron.

2nd. Refine this by means of the Bessemer or open-hearth furnace.

3rd. Then utilise these alloys in the metallurgy of iron and steel by the production of various combinations.

He pointed out that nickel gave iron considerable hardness, rendered it less subject to oxidation, and did not injure its malleability; also, that it would be of service in the manufacture of gun-steel, boiler-plates, and other purposes. Returning to Nouméa in New Caledonia, he erected a smelting furnace, which was put to work on the 10th December, 1877, and the first cast made in the presence of the French governor, officials, and colonists. The metal produced was rich in nickel, from 60 per cent. to 70 per cent.; but unfor-

[1] A very interesting account of Mr. Garnier's work is given in his Paper on "Aluminium and Nickel," in the Bulletin de la Société de l'Industrie Minérale, troisième série, tome iii., 4me livraison, 1869, and again in the Revue Scientifique, March 23rd, 1894; also read before the French Society for the Advancement of Science, in 1895.



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tunately was also found to contain about 2 per cent. of sulphur, a difficulty which had not been expected. There was no difficulty in getting rid of the carbon and silicon by subsequent treatment; but the sulphur obstinately remained, and this was fatal when the alloy was to be used in steel-making operations. A number of experiments were carried out in May, 1878, at the Audincourt Works of Messrs. Reverchon and Saglio; but it was not until the nickel pig as received from New Caledonia was re-melted in basic-lined furnaces, and treated with fluor spar, that the sulphur was at all diminished, namely, to about 1 per cent., which was still too high. Further refining experiments were carried out with the help of Mr. Le Basteur, in the works of the Paris-Lyons-Mediterranean Railway (1879), and by two treatments of the same raw nickel pig, using basic additions, the sulphur was reduced to as low as 0·03 per cent., but this refining meant great extra expense. But, after his fight of six years, Mr. Garnier's processes were abandoned. The matter of nickel manufacture having, however, come up again a few years later, on the 9th January, 1888, he deposited with the Académie des Sciences, under seal, the information not having been before published, a description of his methods.

At the Paris Exhibition of 1889 there was shown, under the auspices of the Minister of Marine in the "Maison Coloniale," a collection of Nouméan ferro-nickel produced in the blast-furnace, cast and forged samples, and also pure nickel, all these specimens having been produced at Septèmes by the firm of Dalifol, Quai Jemmapes, Paris, or elsewhere, under Mr. Garnier's directions, from 1876 to 1882. Mr. Garnier patented his methods in this country on the 20th March, 1876, also later on other improvements, his first public statement being given in the Mémoires de la Société des Ingénieurs Civils, 1877, "On the Treatment of Oxidised Ores of Nickel." Another Frenchman's name has also been specially associated with the manufacture of nickel alloys, viz., Mr. Henry Marbeau, of the Ferro-Nickel Company of Paris, who has done much to help on the successful introduction of the metal.

The further course of events in the development of nickel was, however, to be specially in the New World, largely owing to the opening up of the country by the Canadian Pacific Railway, at the Sudbury nickel mines, which had been worked in a small way since 1884. A magnificent deposit of ore, of very suitable nature, was discovered, and Mr. Garnier was called over to report upon the subject generally. As he expresses it, "The manufacture was taken up with the vigour natural to the Anglo-Saxon race, and the necessary plant installed at a great cost." The nickel works at Brooklyn, near Cleveland (Ohio), were erected largely under the supervision of Mr. Garnier, and the Canadian Copper Company brings its Sudbury ores there to be reduced. A movement is now on foot to complete the production of nickel from the ore to the metal on the spot at Sudbury. The Canadian deposits and methods of producing nickel are dealt with later.

Finally, as regards the new Caledonian deposits, it may be mentioned that Le Nickel Company's last report in March, 1897, stated that whilst in 1896 their mines had been shut down owing to overproduction, at the date in question they were valued at £280,000, in addition to which there were ores in stock, £170,000, with material in process of manufacture and finished products £112,000, or a total of £562,000.

For European use the Sudbury deposits should probably be the most valuable, as they are not more than 3,500 miles away, whilst those of New Caledonia are about 12,000 miles distant.

*United States.*—Whilst Europe does not seem to be endowed by nature with any large or rich nickel ores, New Caledonia's remarkable richness in this

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particular mineral wealth is also equalled, if not surpassed, by a number of deposits in the United States and Canada, the chief of these being the Sudbury ores. Before proceeding to describe the more important of these, a specially curious deposit found in Oregon may be mentioned. This has been described by Mr. W. H. Melville (*Engineering and Mining Journal*, the 11th June, 1892), and termed Josephinite, it being found in Josephine County. Mr. Melville states that metallic nickel is found mixed with silicates in the form of pebbles and smooth boulders. If so, this may be termed a natural alloy of iron and nickel. The deposit was found to be strongly magnetic. The pebbles are greenish black, with bright areas of grey colour. The firmer portions consist of silicate, the other pebbles contain also a silicate insoluble in hydrochloric acid. The origin of the pebbles has not yet been ascertained. It is supposed that as they are found in large quantities in the placer gravel of a stream, they have come from some dike hitherto undiscovered.

ANALYSIS OF PEBBLES.

| | Per cent. |
|---|---|
| Nickel free, Ni | 60·45 |
| Cobalt, Co | 0·55 |
| Iron, free Fe | 23·22 |
| Pyrrhotite, $Fe_7S_8$ | 0·55 |
| Chromite, FeO, $CrO_2$ / Magnetite, FeO, $Fe_2O_3$ | 0·12 |
| Copper, Cu | 0·50 |
| Arsenic, As | 0·23 |
| Chlorine, Cl | 0·04 |
| Silicates (anhydrous) | 12·26 |
| $H_2O$ below 100° C | 0·81 |
| $H_2O$ above 100° C | 1·12 |
| $CO_2$ | trace |
| Volatile matter | 0·70 |
| | 100·55 |
| Nickel combined | 0·25 |
| Iron combined | 1·79 |
| Sulphur | 0·22 |
| Chromium | 0·04 |

ANALYSIS OF SILICATES.

| Composition. | Insoluble Silicate. | Soluble Silicate. |
|---|---|---|
| | Per cent. | Per cent. |
| $SiO_2$ | 45·63 | 38·23 |
| $Al_2O_3$ | 6·58 | 2·34 |
| $Fe_2O_3$ | 8·77 | 15·88 |
| (NiCo)O | Undetermined | 2·49 |
| CaO | 11·03 | 12·14 |
| MgO | 28·01 | 19·85 |
| $Na_2O$ | .. | 0·35 |
| $H_2O$ above 100° C. | .. | 8·72 |
| Total | 100·02 | 100·00 |

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Of special interest is the metallic portion. Two analyses gave—

| —— | 1 | 2 | At ratio. |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Fe . . . . . | 23·36 | 23·09 | 0·41 |
| Ni . . . . . | 60·47 | 60·43 | 1·03 |

From this ratio is deduced the formula $Fe_2 Ni_5$.

The following Table gives a comparison of a few examples of nickeliferous iron, which form an instructive series:—

| —— | Catarinite. | Octibbehite. | Awaruite. | Josephinite. |
|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. |
| Iron . . . . . | 63·69 | 37·69 | 31·02 | 23·22 |
| Nickel. . . . . | 33·97 | 59·69 | 67·63 | 60·45 |
| Atomic ratio Fe : Ni . | 1·14:0·58 | 0·66:1·02 | 0·55:1·17 | 0·41:1·03 |
| Formula . . . . | $Fe_2Ni$ | $Fe_2Ni_3$ | $\left\{ \begin{matrix} 2(FeNi_2) \\ Fe_2Ni_4 \end{matrix} \right\}$ | $Fe_2Ni_5$ |

In the United States the principal deposits in the past have been those of the celebrated Lancaster Gap Mine, discovered in 1718, and worked for copper in 1744, but now worked out. This yellow sulphide ore, "Kupfer-nickel," however, like that found in Bohemia, was thrown aside as worthless, and more than a century had to pass before it was found that this "Kupfer-nickel" was not the worthless material it had been thought to be. Mr. Joseph Wharton, of Philadelphia, acquired the mine in 1862, and started a refinery at Camden (N.J.). Mr. Wharton has since been one of the pioneers in the art of producing and working up nickel, as was well impressed upon those who saw his first large and famous exhibit of wrought nickel at Philadelphia in 1876, and later at the World's Fair, Chicago, in 1893. Mr. Wharton had exhibited as early as 1873 at the Vienna Exhibition. Further information regarding his work is given in a Paper read by Mr. W. P. Blake (of Newhaven, Conn.) at Boston, Mass., before the Institute of Mining Engineers, 1883 (vol. xi. p. 277).

The nickel ores of Orford, in the county of Sherbrooke, Qu., may be also mentioned, as they have proved to be of considerable importance. Dr. Sterry Hunt first described them in his "Geology of Canada," 1863 (p. 738), and they were further dealt with in an interesting Paper by Mr. W. E. Eustis, read at the Philadelphia Meeting of the American Institute of Mining Engineers (vol. vi. 1878). Mr. Eustis may claim to have been one of the very early producers of a nickel alloy, for in January or February 1878, soon after his visit to this district, he melted specimens of millerite from the Orford Mine in a black lead crucible placed on the bank of a Siemens furnace. In about 20 minutes, to his surprise, the contents were found to be liquid and a button of metal was obtained. His next experiment was to run 500 lbs. of the ore through an experimental blast furnace in Prof. Richard's laboratory at the Massachusetts Institute of Technology. An analysis of the small quantity of material which resulted showed iron 71·84 per cent., and nickel 22·70 per cent.

The Lancaster Gap Mine, now worked out, as well as other pyrrhotite deposits at Anthony's Nose, on the Hudson, have been fully described in a Paper read by

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Mr. J. F. Kemp at the Bridgeport meeting of the American Institute of Mining Engineers in October 1894.

Whilst Nature has so richly endowed the United States with vast mineral wealth, at any rate, up to the present time, and beyond the Lancaster Gap Mine, now worked out, no nickel ore deposits of value have been discovered. That this is not for want of energy and exploration is shown by the fact that the well-known American expert in this branch, Mr. Robert M. Thompson, of the Orford Copper Company, stated before the House Ways and Means Committee at Washington, D.C., in June 1897, that though he had sent out an expert at great expense, who had made wide search, no nickel deposits worth working could be found in the United States.

Consequently Canada has apparently the only great supply on the Continent, and it is this fact which has led to the recent important discussion in the Canadian Parliament as to the best methods to be adopted to retain this valuable trade in the country for the benefit of the Dominion industries.

As shown later, at the present time the Canadian Copper Company is largely controlled by an American corporation, the Orford Copper Company, who wish to refine the matte in the States as in the past. Canadian influence is directed to the levying of an export duty on the matte of not more than 10 cents per lb. upon the nickel percentage, and 2 cents per lb. upon the copper percentage of such ores and matte.

A very exhaustive report on the subject has been drawn up and recently adopted by the Toronto Board of Trade, who quote a number of the same references given by the Author in this Paper, and thus indirectly confirm the remarkable figures on p. 77 and elsewhere respecting the great value of the Canadian deposits and their enormous extent. As regards the latter, one fact only will suffice. The Toronto Board of Trade confirms the statement that the Canadian Copper Company alone, chiefly American owned, possess several hundred million tons of high class ore.

It is to be hoped that some mutually satisfactory arrangement will be arrived at which, whilst satisfying Canadian industrial aspirations, will at the same time generously recognize the great service rendered in the past by the American metallurgist and manufacturer in developing this important industry. It is questionable whether nickel and its increasingly important applications would have reached the present stage if it had not been for American enterprise, and for the valuable aid given by the American Government to its introduction for use in the manufacture of armour.

*Canada.*—The chief deposits of Canadian nickel ore are at the Sudbury Mines, Ont., which, owing to their very large area, have during the past 10 years aroused special interest. As soon as it became probable that nickel was to be used in steel manufacture, there was a rush to buy land containing nickel ore deposits, with the usual results. It was found that, important as might be the results obtained with nickel steel, the supply of nickel soon overtook the demand, and consequently prices were quickly cut down to very low figures, specially when it is considered that the production of nickel of the necessary purity is a complex, lengthy, and expensive process. Then the production of nickel steel did not go ahead as was expected. Those accustomed to deal with the production of special alloys of steel know that every new composition has to be carefully worked out, often requiring numbers of years, as well as most careful observations and records to be taken, this necessitating what appears to the outsider a painfully slow development. No doubt this is a fortunate circumstance, or many serious disasters would occur from eager inventors who have often little, or only a general, knowledge of the metallurgy of iron and steel.

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The public is also apt to jump at incorrect conclusions, and think that when a new material is brought forward it is suitable for every purpose under the sun. Many hundreds of replies, which must have damped the ardour of the intending consumers, has the Author of this Paper had to send to inquirers regarding special steels with which he himself has worked, such as manganese, chromium, and other steels. If the inquirers had only read what has been clearly and specifically stated in Papers of the Author and other investigators, most of the inquiries would have been entirely unnecessary. As a rule, each particular alloy has its own special use, and there is no philosopher's stone discovered or to be expected which will make one steel suit every purpose.

One of the best descriptions of the nickel ores of Sudbury (Ont.) was written several years ago by Mr. John D. Frossard, B.Sc. This has been published by Messrs. G. Philip and Son, 33 Fleet Street, London. There are also excellent papers by Mr. A. G. Charleton, A.R.S.M., read before the Society of Arts ("Nickel: Its History, Uses, and Distribution," 4th May, 1894, and "The Dressing and Metallurgical Treatment of Nickel Ores," 22nd May, 1895). An important Paper was also read at the Ottawa meeting of the American Institute of Mining Engineers (1889), by Dr. E. D. Peters, on the Sudbury nickel and copper deposits.[1]

Turning now to the history of the Canadian developments, it appears that Mr. Alex. Murray, in 1854, was the first to draw attention to the deposits near Sudbury, and he went so far as to have an analysis of the ore made, which showed small quantities of nickel and copper; but it was not until early in 1884, during the construction of the Canadian Pacific Railway, when the cutting pierced a small hill near Sudbury, that the deposit now known as the Murray Mine was discovered. Sudbury is about 440 miles west of Montreal, on the Canadian Pacific Railway, and about 840 feet above mean sea level. This nickel region, of which Sudbury is the centre, is believed to extend from the western extremity of the north shore of Lake Huron to the boundary of the province of Quebec at Lake Albitilbi, or a distance of over 300 miles, with a width of 70 to 80 miles, and in the neighbourhood of Sudbury alone the deposits are known to be immense. An official report to the Navy Bureau of the United States Government stated that many millions of tons of ore were immediately in sight. The report of the Toronto Board of Trade Official quotes these figures, and being quite recent,[2] no doubt confirmation has been obtained of the remarkable figures given in the American report by Commander Folger and Lieutenant Buckingham to the Secretary of the United States Navy, 14th October, 1890, where it was stated that "the Canadian Copper Company alone own 650 million tons[3] of ore above ground surface." Evidently the world need not fear being short of nickel ores.

The American production of nickel, almost entirely from Canadian ores, reached a total of 1,650 tons in 1896, as against 1,200 tons in 1895. But of this nearly 60 per cent. was in the form of oxide and sulphide, the remainder only being metallic nickel. To produce this quantity of metal, about forty-five to fifty times this quantity of ore has to be raised, but, of course, in addition to

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[1] Incidentally it may be mentioned that on good authority (the Toronto Board of Trade) it is stated that a large share of the future supply of platinum for the world will be got from these mines.

[2] A full account of this report is given in the *Iron Age*, May 5th, 1898.

[3] In *Iron Age*, May 12th, 1898, it is stated that this estimate is much exaggerated.

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the nickel obtained there is almost an equal quantity of copper. The highly important Sudbury deposits are further dealt with when considering the questions of extraction and refining.

*Extraction and Treatment of Nickel Ores.*—The principal ores of nickel are the hydrous silicate of nickel and magnesia (Garnierite), and nickeliferous pyrrhotite and chalcopyrite. Nickel also occurs in workable quantities, as sulphide (millerite), arsenide (niccolite), and arseniate (annabergite). Garnierite is a brittle mineral of a pale green colour and glinting to dull lustre. Millerite is a brass-yellow in colour, with a grey iridescent tarnish. Niccolite has a pale coppery red hue and metallic lustre, its streak being a pale brownish red.

The American and Canadian deposits previously referred to are as follows:—

*The Lancaster gap mine.*—This was worked out in 1893; reference to it at any length here is, therefore, unnecessary. It was during a considerable time the chief source of the ore for America.

The Sudbury district now rivals New Caledonia as the most important source of the world's supply. This lies in the course of a belt of Huronian rocks, within which occur many inliers of gneiss and red quartz syenite, the age of which is uncertain. The ore deposits of the region occur in both these formations. The ore in all cases consists of a mixture of chalcopyrite and nickeliferous pyrrhotite, the nickel in the latter ranging from 1 per cent. to 3 per cent. Specimens of millerite are found occasionally and also the unique mineral sperrylite (arsenide of platinum). The area over which nickel has been found in this district extends from Wallace Mine, on Lake Huron, in the vicinity of La Cloche, north-eastward to the north side of Lake Wahnapitae, a distance of about 70 miles; and from the south-eastern limit of the Huronian rocks of Sudbury, north-eastward to Geneva Lake, a distance of about 50 miles. The principal mines are controlled by the Canadian Copper Company, of Sudbury (Ontario), and Cleveland (Ohio); the Dominion Mineral Company, of Montreal, Canada; H. H. Vivian and Company, of Swansea; and the Drury Nickel Company, of Chicago, Illinois. The Canadian Copper Company owns thirteen ore-beds, five being of high grade. They were originally worked for copper, and it was not until a parcel of ore had been shipped for smelting that its true character was discovered. Although some of the mines have reached a depth of 600 feet at a 40° slope, the ore shows no alteration in character, nor are there any signs that the bottom of the deposit is near. About one-third of the ore is rejected by handpicking. After this it averages 1½ per cent. to 3 per cent. of nickel, and from 1 per cent. to 4 per cent. of copper.

The composition of commercial nickel, nickel matte, nickel oxide, &c., is shown by the Table on pages 90-91, from an article by Mr. S. H. Emmens.[1]

The Table on page 92 gives a list of analyses by the Author of various kinds of nickel and its iron alloys.

The analyses Nos. 1810 and 1811 were made in order to ascertain what quantity of carbon was present in the nickel in question, and in what form; also whether it would take up carbon during the cementation process. Apparently that process produced a further transformation of combined into graphitic carbon.

There are about one hundred and five minerals known to be nickeliferous, but very few of these are of industrial importance. Practically the world's supply is derived from two sources; namely, the nickel magnesia silicate

[1] *Engineering and Mining Journal*, November 26th, 1892.

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| Substance. | Analysis from | Date. | Ni. |
|---|---|---|---|
| | | | Per cent. |
| Matte (Swedish) . . . | Wagner's Chem. Tech.. 8th ed. . . . . | .. | .. |
| „ (Sudbury) . . . | Canadian Copper Co. . | 1889 | 14·84 |
| „ „ . . . | „ „ „ . | 1889 | 13·04 |
| Bessemerized (Sudbury) . | „ „ „ . | 1892 | .. |
| „ (New Caledonia) . . . . . | Thorpe's Dict. of Applied Chem. . . . . | .. | .. |
| "Fonte" (New Caledonia) | Thorpe's Dict. of Applied Chem. . . . . | .. | .. |
| Nickel oxide (Sudbury) . | Orford Copper Co. . . | 1891 | .. |
| „ „ (New Caledonia) . . . . . | Soc. de Nickel . . . | 1891 | .. |
| Artificial nickel ore . . | E. F. Wood . . . . | 1891 | .. |
| Nickel (German) . . . | Lassaigne . . . . . | .. | 56·75 |
| „ ( „ ) . . . | „ . . . . . | .. | 54·60 |
| „ (English) . . . | „ . . . . . | .. | 73·30 |
| „ (New Caledonia) . | Christofle and Bouilhet . | 1881 | .. |
| Disk nickel (New Caledonia) . . . . . | Thorpe's Dict. of Applied Chem. . . . . | .. | .. |
| Cast nickel . . . . | Gard . . . . . | .. | 97·44 |
| Sheet nickel (German) . | F. P. Dewey . . . . | 1891 | 97·05 |
| Rolled anode (German) . | „ . . . . | 1891 | 97·63 |
| Disk nickel . . . . | „ . . . . | 1891 | 97·38 |
| Cube „ . . . . | „ . . . . | 1891 | 96·757 |
| Grain „ . . . . | „ . . . . | 1891 | 94·988 |
| „ „ . . . . | „ . . . . | 1892 | 96·29 |
| Cast nickel anode . . | „ . . . . | 1892 | 83·68 |
| „ „ „ . . | „ . . . . | 1891 | 82·776 |

[1] and [2] Average of three assays.

[3] "It showed by qualitative analysis slight traces of arsenic, antimony and aluminium, and a perceptible amount of silicon. No other metal or phosphorus was found."—Note by Mr. Dewey.

[4] "Showed some silicious residue."—Note by Mr. Dewey.

[5] "A small amount of hard, gritty grains left on dissolving the metal."—Note by Mr. Dewey.

[6] "It showed by qualitative examination the slightest traces of arsenic and antimony, some aluminium, and considerable silicon and calcium. Distinct

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| Co. | Ni + Co. | Fe. | Cu. | S. | C, $SiO_2$ and other Impurities. |
|---|---|---|---|---|---|
| Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| .. | 26·00 | 16·33 | 31·67 | 26·00 | .. [1] |
| 0·27 | 14·71 | 31·00 | 27·06 | 26·90 | 0·92 |
| 0·20 | 14·04 | 31·47 | 26·76 | 27·00 | 0·95 |
| .. | 35·93 | 1·09 | 40·98 | 19·71 | 2·29 [2] |
| .. | 67·17 | 11·90 | .. | 17·08 | 3·85 |
| .. | 67·95 | 25·87 | .. | 1·95 | 2·90 |
| .. | 74·60 | 1·51 | 1·25 | .. | 1·45 |
| .. | 77·92 | 0·25 | 0·09 | .. | .. |
| .. | 48·23 | 23·87 | trace | 0·264 | 27·636 |
| .. | 56·75 | 12·55 | 27·50 | .. | 3·70 |
| .. | 54·60 | 11·30 | 30·10 | .. | 4·00 |
| 22·10 | 95·40 | 1·00 | trace | .. | 3·00 |
| .. | 97·75 | Mn 0·36 | .. | .. | 1·79 |
| .. | 98·83 | 0·72 | .. | .. | 0·45 |
| trace | 97·44 | 0·301 | | 0·104 | 2·155 |
| 1·858 | 98·908 | 0·829 | 0·498 | 0·012 | 0·042 [3] |
| 1·19 | 98·82 | 0·75 | 0·115 | 0·04 | 0·24 [4] |
| 1·70 | 99·08 | 0·06 | 0·68 | 0·013 | 0·167 [5] |
| 1·586 | 98·343 | 0·32 | 0·113 | trace | 1·224 |
| 0·856 | 95·844 | 0·354 | 0·047 | trace | 3·755 [6] |
| 0·93 | 97·22 | 1·92 | 0·20 | 0·104 | 0·556 [7] |
| trace | 83·68 | 7·10 | 0·15 | 0·19 | 8·88 [8] |
| 1·133 | 83·909 | 12·091 | 0·103 | 0·05 | 3·847 [9] |

grains of slag were found. No other metal or phosphorus was found."—Note by Mr. Dewey.

[7] "There is some Si and considerable As in this sample."—Note by Mr. Dewey.

[8] "It contained a considerable amount of tin, probably 7 per cent. There is also considerable silicon present."—Note by Mr. Dewey.

[9] "It showed on qualitative analysis slight traces of arsenic and antimony, some aluminium and calcium and considerable silicon. No other metal or phosphorus was found."—Note by Mr. Dewey.

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ANALYSES BY THE AUTHOR.

| Analysis No. | Date. | Name. | Address. | Description. | Price per lb. | Analysis. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | C. | Si. | Mn. | Ni. | Fe. |
| | | | | | s. d. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| 6,601 | .. .. | Tucker & Co. | Sheffield | Nickel | .. | .. | 0·30 | None | 98·54 | .. |
| 6,605 | April 15, 1890 . | Nickel Co. | Birmingham | Best well reduced nickel | 2 0 | .. | 0·26 | .. | 97·60 | .. |
| 6,610 | .. .. | Keiffenheim | Newcastle-on-Tyne | 58 per cent. nickel | 1 9½ | 0·67 | .. | .. | 58·63 | 36·50 |
| 13,078 | February 27, 1891 | Nickel Co. | Birmingham | Best cake nickel | .. | .. | .. | .. | 98·10 | .. |
| 13,088 | February 15, 1892 | Nickel Steel Syndicate | London | Nickel spiegel | .. | 0·20 | 0·19 | 11·77 | 33·10 | 51·70 |
| 13,089 | February 22, 1892 | Nickel Steel Syndicate | ,, | Ferro-nickel | .. | 1·34 | .. | .. | 48·5 | 48·1 |
| 13,095 | April 10, 1893 . | Mappin & Webb | Sheffield | Ferro-nickel | .. | 2·00 | .. | .. | 49·2 | 47·74 |
| 1,794 | November 30, 1893 | Mappin & Webb | ,, | Shot nickel | 1 9 | .. | .. | .. | 99·16 | .. |
| 1,797 | November 25, 1895 | H. R. Merton & Co. | London | Pure nickel | 1 0 | .. | .. | .. | 98·38 | .. |
| 1,803 | June 1, 1896 . | Mappin & Webb | Sheffield | Granular nickel | 1 1½ | .. | .. | .. | 98·22 | .. |
| 4,694 | December 16, 1897 | Mond Nickel Co. | .. .. | Metallic nickel | .. | .. | .. | .. | 99·55 | Co·045 |
| | | | | | | C. | Gr. | | | |
| 1,810 | Sample of nickel bar before cementation. | | | .. .. | .. | 0·30 | 1·36 | .. | .. | .. |
| 1,811 | Sample of nickel bar after cementation. | | | .. .. | .. | 0·05 | 1·56 | .. | .. | .. |

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(Garnierite) of New Caledonia, and the nickeliferous pyrrhotite of Canada.[1] Their composition is as follows :—

*Garnierite.*—Nickel, 0·24 per cent. to 35 per cent.; magnesia, 2½ per cent. to 37 per cent.; silica, 35 per cent. to 67 per cent.; alumina, 0·20 per cent. to 15 per cent.; lime, nil per cent. to 2 per cent.; sulphuric anhydride, nil per cent. to 0·83 per cent.; water, 5 per cent. to 18 per cent.

*Pyrrhotite.*—Nickel, trace to 12 per cent.; magnesia, nil per cent. to 0·86 per cent.; iron, 49 per cent. to 62 per cent.; cobalt, trace to 1·00 per cent.; copper, trace to 0·54 per cent.; sulphur, 36 per cent. to 43 per cent.; arsenic, nil to trace.

*Treatment of Garnierite.*—The ore is smelted in a low blast furnace with coke and gypsum alkali waste or salt cake in order to remove the silica, magnesia, &c., in the form of a slag, and to produce a regulus of nickel and iron. The latter is then subjected in a reverberatory furnace to a series of alternate roastings and fusions with sand, whereby the sand is gradually slagged off and almost pure nickel sulphide finally obtained, which may be converted into oxide by calcination. Bessemerizing is sometimes resorted to as a substitute for the first roasting and fusion of the cupola matte.

*Treatment of Pyrrhotite.*—The ore is stacked in raised heaps, containing hundreds of tons and ignited by means of cord wood beneath the heap. The burning is continued for several weeks, and results in the removal of the sulphur and a partial oxidation of the iron. The roasted ore is then smelted with coke in a low-blast furnace, the gangue serving as a sufficient flux, the product being a regulus of nickel, iron, and copper. This regulus is then Bessemerized in converters lined with silica, which substance unites with the oxidised iron to form slag, while the copper and nickel remain as sulphides. The enriched matte is then calcined in a reverberatory furnace to remove most of the sulphur, afterwards roasted with salt, and the copper chloride removed by lixiviation. If a considerable amount of iron remains with the nickel, the lixiviated material is dried, mixed with a little pyrite (or other sulphur compound) and sand, and fused in a reverberatory furnace so as to slag off the iron and leave almost pure nickel sulphide, which is then converted into oxide by calcination.

*Reduction of the Nickel Oxide.*—The oxide obtained as above described is, if pure, intimately mixed with charcoal and heated to whiteness in graphite crucibles, where it assumes the metallic condition, and when molten is granulated by being poured into water. Sometimes the oxide is mixed further with finely powdered wood charcoal, or with flour or starch made plastic with molasses, the mixture is moulded into cubes, discs, or coarse grains, which are then packed in crucibles with charcoal, and exposed to a heat short of that required for fusion.

In the Ontario Bureau of Mines Report for 1891, it is stated that including the total amount paid for labour (not including roasting or smelting), to which must be added an allowance for fuel, timber, repairs, &c., the cost per ton of pyrrhotite delivered at the breaker cannot be estimated at less than $5·00 per ton.

In the cost of Garnierite, as the mines are situated high in the mountains, at a distance from the coast, and comparatively inefficient labour, with carriage expenses to Europe, it may be estimated that the total cost of the ore delivered in the Scotch or French reduction works is not less than $20·00 per ton. As, however, it contains an average of 10 per cent. of nickel, whereas the pyrrhotite

[1] Mr. Stephen H. Emmens' "Mineral Industry," on "The Metallurgy of Nickel."

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averages only 2·60 per cent., the prime cost of the raw material for treatment—that is, the nickel in the ore condition—is about the same in both cases, namely, 10 cents per pound.

*Costs of Production.*—Breaking, 30 cents per ton; heaping and roasting, 50 cents; cupola smelting, $2·50; Bessemerizing, $2·00; reverberatory calcining, $1·25; reverberatory fusion, $3·54; refined sulphide roasting, $5·00; chlorination and lixiviation, $4·00. Thus the total cost of 1 ton of nickel oxide, containing, say 76 per cent. metallic nickel, may be thus estimated:—

| I.—From Garnierite. | $ |
|---|---|
| Smelting for matte, 7·6 tons at $2·50 | 19·00 |
| First calcination, 2·0 tons at $1·25 | 2·50 |
| First fusion, 2·0 tons at $3·54 | 7·08 |
| Second calcination (this may be run up to five operations), 1·75 tons at $1·25 | 2·19 |
| Second fusion, 1·75 tons at $3·54 | 6·20 |
| Pulverizing of refined sulphide | 0·50 |
| First roasting of refined sulphide | 5·00 |
| Second pulverizing | 0·50 |
| Second roasting | 5·00 |
| Total | 47·97 |

| II.—From Pyrrhotite. | $ |
|---|---|
| Breaking, 29 tons at $0·30 | 8·70 |
| Heap roasting, 29 tons at $0·50 | 14·50 |
| Smelting for matte, 30 tons at $2·50 | 75·00 |
| Bessemerizing, 5 tons at $2·00 | 10·00 |
| First calcination, 2½ tons at $1·25 | 3·15 |
| Chlorination and lixiviation, 2½ tons at $4·00 | 10·00 |
| Second calcination, 1¾ tons at $1·25 | 2·19 |
| Second fusion, 1¾ tons at $3·54 | 6·20 |
| Pulverizing of refined sulphide | 0·50 |
| First roasting of sulphide | 5·00 |
| Second pulverizing | 0·50 |
| Second roasting | 5·00 |
| Total | 140·74 |

If the oxide be sufficiently pure to require no intermediate refining, and if it be run direct into granulated metal by reduction in crucibles, the cost incurred for crucibles, fuel, charcoal, labour, repairs, &c., is about 8 cents per pound of nickel produced. Hence the ultimate cost of the metal is as follows:—

| I.—From Garnierite. | $ |
|---|---|
| Mining and transport | 0·10 |
| Conversion into oxide | 0·03 |
| Reduction into metal | 0·08 |
| Allowance for loss in working | 0·01 |
| Total | 0·22 |

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| II.—From Pyrrhotite. | $ |
|---|---|
| Mining and transport | 0·10 |
| Conversion into oxide | 0·09 |
| Reduction into metal | 0·08 |
| Allowance for loss in working | 0·04 |
| Total | 0·31 |

These figures are based upon the supposition that the work is carried out on a considerable scale, and in a locality where fuel and labour are cheap; also that the ores to be treated are free from any perceptible quantity of arsenic or other impurity.

*Processes of Reduction.*—Although the modern "dry" processes of reduction are cheaper than the "wet" methods formerly employed, still the demand for extreme purity in the metallic product necessitates much care and, consequently, expense. In this latter respect the New Caledonia ore, from its purity, has very great additional advantage as compared with the Canadian ores.

Special attention has been paid to purity of product by the Orford Copper Company, Constable Hook, near Bayonne (N.J.), who work specially for the American Government, supplying the nickel oxide used in the manufacture of its armour-plates. In 1892 this company produced no less than 980 tons of fine nickel in the oxide, representing a value of £144,000. Of this, 350 tons were furnished to the United States Government at a price of £52,000. In 1896 they produced for American consumption, chiefly for the Government, about 420 tons of nickel; in 1897, about 470 tons, also exporting in addition 1,668 and 1,767 tons respectively.

There is a very excellent article in Rothwell's "Mineral Industry" of 1894, p. 459, by Mr. Titus Ulke, on the treatment of pyritous ores containing copper and nickel. There was also amongst the excellent exhibits at the Chicago Exhibition, in the Mines building, a very clear statement of the various processes used in the extraction, accompanying the Wharton nickel exhibits.

At the Canadian Copper Company's Works, Sudbury, ores containing on an average 3 per cent. nickel and copper are heap roasted. The ore in the coarse and fine states is piled in lots of 600 tons to 3,000 tons to heights of 5 feet, 10 feet, and 15 feet. Each heap burns from 6 weeks to 20 weeks, during which the sulphur is lowered to about 7 per cent. The iron is in large part oxidized to a ferrous oxide, and the diorite is thoroughly disintegrated by the swelling and oxidation of the ore.

After being thoroughly roasted it is taken to the smelters, which are furnaces of the Herreshoff type, water jacketed, about 9 feet in height to charging door, of oval section, 6 feet 6 inches by 3 feet 3 inches, with 2-inch water space, and provided with an exterior brick-lined, water-cooled fore hearth or well. Each furnace has a capacity of about 125 tons of ore or 15 tons of matte in 24 hours, two furnaces being always in operation. The matte is tipped into conical cast-iron matte-pots, in which it is allowed to cool. The process of smelting is very economical, the ore in itself furnishing the exact ingredients necessary for fluxing.

About 15 per cent. of Connelsville coke is used to reduce the ore to matte, that is, about 1 ton of coke makes 0·9 lb. of cupola matte. The average grade of this matte will analyse: copper, 20 per cent. to 25 per cent.; nickel, 18 per cent. to 23 per cent.; iron, 25 per cent. to 35 per cent.; sulphur, 20 per cent. to

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30 per cent. If picked ore is used, the matte is sometimes obtained with as high as 52 per cent. nickel. Any desired proportion of copper and nickel can be made from selected ores. The grade can be varied to suit the consumer, either high copper and low nickel, or low copper with high nickel. It is found that as the mines deepen the ore changes in character, from a distinctly copper ore at the surface to a distinctly nickel ore at the lower levels. Copper Cliff Mine produced on the first level, chalcopyrite, in which the nickel was found by accident after shipments had been made of the ore as copper ore alone. On the fourth and fifth levels the ore was about 4 per cent. copper and 4·5 per cent. nickel, while on the seventh level many stopes show an average of 0·5 per cent. copper to 8 per cent. and 10 per cent. nickel.

The next step is the refining of the cupola matte. At the Canadian Copper Refinery at Sudbury, the matte re-melted in cupolas is run into converters of the Bessemer type and similar to those used in refining copper. This plant has a capacity of about 25 tons of cupola matte or 15 tons of Bessemer matte in 24 hours. The iron is almost entirely removed, the sulphur lowered to from 5 per cent. to 15 per cent., and the copper and nickel raised to about 45 per cent. and 40 per cent. respectively. As there are no firm reactions to guide the operator, the point at which to stop the blowing after the iron had been removed and before the nickel has commenced to slag in undue amounts, is one in which much skill is required. All converter slags are returned to the cupolas for re-melting. The converter matte is cast in slabs of 3 feet square and about 3 inches thick, weighing about 1,500 lbs. each. A fair average analysis of the converter matte is copper, 43 per cent.; nickel, 39 per cent.; iron, 0·3 per cent.; sulphur 14 per cent.; with small quantities of gold, silver and platinum.[1] In Bessemerizing the matte, the process branches into two distinct parts. For the manufacture of copper-nickel alloys for use in German silver, the Bessemer matte, after roasting to remove all the sulphur, can be reduced direct to alloy either by charcoal or reducing gases. A refined copper-nickel alloy containing 50 per cent. copper and 49 per cent. nickel, with very small amounts of iron, silicon, and carbon, is produced direct from Bessemer matte. This alloy is of great service to German silver manufacturers, as by adding the necessary amount of zinc the alloy is at once ready for commercial use. This "50-50" alloy is almost indistinguishable from pure nickel.

In the Orford[2] process carried out chiefly at the Bayonne works (N.J.) of the Orford Copper Company, the metals in the matte are reduced by a preliminary treatment, either as above described by the Bessemer process, or by ordinary calcining and melting in a low-blast furnace to a point where the metals are present substantially as sub-sulphides. This matte is then melted with an alkaline sulphide (in practice with salt cake, that is, sulphate of soda, which in a blast furnace is reduced to sulphide of soda), and a reaction follows in which the copper and iron take the sulphur from the soda. By adding the proper pro-

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[1] The latest available information shows that Sudbury nickel-copper matte averages about 20 per cent. of nickel, and 20 per cent. to 25 per cent. of copper. Roughly, it is estimated that 6 tons of ore produce 1 ton of matte. A similar estimate was made by Dr. Edward Peters, junior, late manager of the Canadian Copper Company, when giving evidence before the Royal Commission on the Mineral Resources of Ontario.

[2] The Orford process is a kind of revival of the methods used by Vivian, viz., smelting ore or matte with $NaSo_4$, crude salt cake, or any fusible alkali lphate or sulphide whereby copper is slagged off and NiS produced.

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portions of salt cake, the bulk of the iron and copper are converted into sulphides, and mixing with the soda make a very fluid mass, from which the sub-sulphate of nickel separates by gravity, and, on cooling, leaves in the tops the bulk of the copper and iron and the soda, and in the bottoms the bulk of the nickel. On exposure to the weather, the soda in the tops is converted into caustic soda; these tops are now mixed with matte and re-melted, whereby the caustic soda is converted into sulphide of soda at the expense of the nickel, leaving the latter in a semi-metallic state, and again a top and bottom is formed, with copper and iron in the top and nickel in the bottom. By properly balancing these various treatments, a pure sulphide of nickel is at last obtained, which, by calcining, is converted into an oxide. A further perfection of this process has given laboratory metal of 99·90 per cent. purity. Hitherto the process employed for the production of nickel from its oxide has been the reduction of this oxide, either loose or compressed, into cubes, with charcoal in crucibles. This yields a product which, in the case of cube nickel, is not strictly a homogeneous metal, but a loose sponge of metallic particles, which retain all the impurities contained in the oxide, plus from 0·5 per cent. to 2 per cent. of carbon. The Canadian Copper Company's metal, produced in their Cleveland (Ohio) refinery, is, however, a solid metal, having been melted direct from the oxide, and the carbon and silicon entirely removed. A casting weighing 4,500 lbs. of nickel, exhibited at the World's Columbian Exposition, and made at these Cleveland Works, had the following composition:—

| Ni. | Fe. | S. | Cu. | Si. | C. | Sn. |
|---|---|---|---|---|---|---|
| Per cent. 98·78 | Per cent. 0·30 | Per cent. 0·07 | Per cent. 0·76 | Per cent. 0·19 | Per cent. None | Per cent. None |

It is usual to add a small quantity of magnesium or aluminium to make it solid and free from blowholes. This discovery, claimed by Fleitman, is reported to have been of the greatest importance for certain classes of work.

The following are the various processes used in extracting nickel from its ores:—

(1) The alkaline sulphide process, for extracting nickel from Canadian matte.

(2) The American process, for extracting nickel from Canadian pyrrhotite.

(3) The Gossan process, for extracting nickel from Canadian pyrrhotite. This has not been successful at the Canadian Copper Company's Works.

(4) The ordinary wet process, for extracting nickel and cobalt from calcined ores, speiss, and matte.

(5) The European process, for extracting nickel from silicate ore imported from New Caledonia.

*European Process.*—In Europe the ordinary low-grade nickel matte is refined either in reverberatory furnaces (English method) or by Bessemerizing. The reverberatory refining requires two operations, each of which includes two phases, namely, roasting, and fusion with quartzose sand to scarify the iron. Each furnace treats 2 tons in 24 hours, and consumes 2 tons of coal. Samples are taken in the course of the operation, which lasts about 8 hours, in order to roast the work as soon as the iron has disappeared, so as to prevent the passing of the nickel into the slag. The latter is not thrown away, because it contains from 2 per cent. to 2·5 per cent. of nickel, and makes an excellent flux. The



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first operation in the reverberatory gives matte with 2·5 per cent. to 3 per cent. iron, the second 0·5 per cent. to 0·75 per cent. at most.

The refined matte contains at least 16 per cent. of sulphur, in order to be easily pulverised for subsequent treatment. The matte freed from iron has the following composition:—Ni 75 per cent., S 24 per cent., Fe 0·5 per cent., impurities 0·5 per cent.

The total impurities should not amount to over 1 per cent., for the subsequent operations only remove sulphur. The matte is crushed to sixty-five mesh, and is treated in a large roasting furnace (33 feet long by 8 feet wide, with fire doors on one side), in which the charge is rabbled along towards the fire bridge. The charge is about 1,400 lbs., and the operation lasts 8 hours, or less if copper is present. About 1½ ton per 24 hours is treated, using 1 ton of coal. The temperature is kept at a dark heat to prevent fusion. The operation lasts about 6 hours, and produces an oxide with a small proportion, about 1 per cent., of sulphur and sulphates. This material is subjected to another roasting after crushing to 120 mesh, and the temperature is raised to a bright red heat. The resulting oxide, or oxides, for copper oxide is not eliminated, which should contain not more than 0·04 per cent. of sulphur, is formed into cubes or other desirable shapes, with water and flour, and reduced with charcoal in a suitable furnace. The copper must be separated from the nickel by one of the wet methods.

The Bessemerizing requires much less time than the reverberatory method. At Havre the melted matte is run into a converter of a ton capacity, and blown with a pressure of 40 centimetres of mercury. The temperature rises, and the quartzose mixture is thrown on the surface for scarifying the iron. If the matte does not contain more than 36 per cent. of iron, the latter can be removed in about 80 minutes. If more than this, the bath should be skimmed at least once after the first 25 minutes, and a new proportion of the flux added. After the final skimming, and when the nickel is found to be oxidising in its turn, the refined matte, containing 0·5 per cent. iron, is run off. Nearly all the arsenic, antimony, and sulphur are carried off by the blast or into the slag. This slag contains 14 per cent. to 15 per cent. of nickel, mostly in the form of prills carried into the composite mass by the blast, part of which is recovered by running the slag into pots and allowing the metal to sink to the bottom. The slag must be returned to the furnace.

It would seem natural to continue the action of the blast in the converter upon the matte freed from iron, in order to burn out the sulphur and so obtain refined nickel, which would only then need to be heated in a reducing atmosphere to reduce the nickel oxide which might be formed, as is done with copper. But numerous attempts appear to show that it is not possible to succeed in this way. After the iron has been removed the nickel not only oxidises with the sulphur, but the temperature falls, because the combustion of the sulphur, which is lessened by the affinity of sulphur for nickel, does not compensate for the cooling due to the injection of the air. The bath then tends to solidify, and this effect is the more speedy as the uncombined nickel produced can only remain in the liquid state at a very high temperature, near that of molten iron.

At the Chicago Exhibition excellent schemes for extracting the ore were shown diagrammatically, those on page 99 being the principal.

The alkaline sulphide process was first suggested by C. Schafhautl in 1839, followed by W. Jefferies in 1840, T. Bell in 1842, and W. Gossage in 1845 and 1850. It has since been perfected by the Orford Copper Company at Constable's Hook, N.J., while preparing the nickel oxide required for use in the manufacture of nickel-steel armour-plates for the American Government.

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THE ALKALINE SULPHIDE PROCESS FOR EXTRACTING NICKEL FROM CANADIAN MATTE.

| Materials. | Reactions. | Products. |
|---|---|---|
| | *Stage I.—Concentration Smelting.* | |
| 1. Matte.<br>2. Sulphate of soda.<br>3. Coke. | 1. The $Na_2SO_4$ is reduced to sulphide.<br>2. Part of the iron and copper unite with the sodium sulphide. | 1. "Tops," consisting of highly cupriferous and ferruginous matte, which goes to the next stage.<br>2. "Bottoms," highly nickeliferous matte, which goes to the third stage. |
| | *Stage II.—"Tops" Smelting.* | |
| 1. Weathered "tops" from the first and third stages.<br>2. Matte.<br>3. Coke. | 1. The soda in the tops takes up some S from the Ni in matte, and forms a sulphide which unites with part of the iron and copper. | 1. "Tops" as in first stage.<br>2. "Bottoms" as in first stage. |
| | *Stage III.—"Bottoms" Smelting.* | |
| 1. "Bottoms" from first and second stages.<br>2. Sulphate of soda.<br>3. Coke. | 1. The sulphate of soda becomes reduced to sulphide.<br>2. Most of the iron and copper unite with the sodium sulphide. | 1. The "Tops" which go to the second stage.<br>2. Highly nickeliferous sulphide, which goes to the fourth stage. |
| | *Stage IV.—Removal of Iron.* | |
| 1. Sulphide from the third stage.<br>2. Sand.<br>3. Fuel. | 1. Most of the iron and part of the nickel are oxidized by roasting.<br>2. The silica combines with the oxide.<br>3. The nickel retains its sulphur. | 1. A ferruginous and slightly nickeliferous slag, which goes to waste.<br>2. Nickel sulphide, which goes to the fifth stage. |
| | *Stage V.—Removal of Sulphur (finishing roast).* | |
| 1. Nickel sulphide from the fourth stage.<br>2. Nitrate of soda in small quantities.<br>3. Fuel. | The sulphur and nickel are both oxidized. A little salt may be added to convert lime adhering to the bottoms as slag or sulphide into $CaCl_2$, which is afterwards removed by washing. | 1. Gases which escape.<br>2. Nickel oxide, which is sold to nickel steel makers, or is reduced direct to refined metal. |

The process of making the nickel oxide into bricks with lime, charcoal, &c., was tried by the Canadian Copper Company in 1892 and proved a complete failure. Garnier ran NiO bricks through his cupola and made a pig nickel, which he tried to refine on a silica bottom, but he could neither make pig nickel continuously nor refine it after he had it made.—DAVID H. BROWNE.

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*American Process.*—The American process of extracting nickel from Canadian pyrrhotite is as follows:—

REACTIONS.

| Materials. | Reactions. | Products. |
|---|---|---|
| | *Stage I.—Heap Roasting.* | |
| 1. The ore in small fragments built up in heaps.<br>2. Cord wood. | 1. Much of the sulphur is burnt off.<br>2. Much of the iron is oxidised to ferrous and ferric oxide. | 1. Gases which escape.<br>2. Partly desulphurized and oxidized ore which goes to the next stage. |
| | *Stage II.—Smelting for Matte.* | |
| 1. The roasted ore from the first stage.<br>2. Nickeliferous slag from the 2nd and 3rd stages. | 1. The gangue of the ore unites with the iron oxide to form slag.<br>2. The metal of the ore unites with the sulphur to form matte. | 1. A slag which goes to waste when it is not nickeliferous enough for resmelting.<br>2. Nickel, iron, copper matte, which goes to the next stage. |
| | *Stage III.—Bessemerizing.* | |
| 1. Matte from the second stage.<br>2. Silica.<br>3. A blast of air forced through the molten material. | 1. Some of the sulphur and almost all of the iron are oxidized.<br>2. The silica unites with the iron oxide. | 1. A slag which goes to waste when not nickeliferous enough for resmelting.<br>2. A matte very low in iron and rich in nickel and copper. |
| | *Stage IV.—Removal of Cu.* | |
| 1. The material from the third stage.<br>2. Salt.<br>3. Fuel.<br>4. Water and a jet of steam. | 1. The sulphur is oxidised; the sulphuric acid combines with the Na of the salt.<br>2. The chlorine of the salt combines with the copper.<br>3. The water dissolves out the copper chloride. | 1. A solution containing most of the Cu, and some Ni, Fe, Cu, Mn, which is then subjected to the ordinary process.<br>2. A residue composed chiefly of Ni and iron oxidized, which goes to the next stage. |
| | *Stage V.—Removal of Fe.* | |
| 1. The oxides from the fourth stage.<br>2. Sand.<br>3. Sodium sulphide.<br>4. Charcoal.<br>5. Fuel. | 1. The silica unites with the soda and iron oxide, and<br>2. The Ni and other metals unite with the S. | 1. A slightly nickeliferous slag which goes to waste.<br>2. A highly nickeliferous matte which goes to the next stage. |

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REACTIONS—*continued.*

| Materials. | Reactions. | Products. |
|---|---|---|
| | *Stage VI.—Removal of S.* | |
| 1. The material from the fifth stage.<br>2. Nitrate of soda in small amounts.<br>3. Fuel. | 1. The sulphur and remaining metals are all oxidized. | 1. Gases which escape.<br>2. Metallic oxides. |
| | *Stage VII.—Production of Metallic Nickel.* | |
| 1. The oxides from the fifth stage.<br>2. Charcoal.<br>3. Sand.<br>4. Soda ash.<br>5. Fuel and a stream of water. | 1. The sand, soda and iron combine as a slag.<br>2. The oxides part with their O to the C.<br>3. The molten metal when poured into the stream of water becomes shotted. | 1. Gases which escape.<br>2. A slag which goes to waste when it is not nickeliferous enough for resmelting.<br>3. Granulated nickel which comes into the market. |

The Bessemerized nickel-copper matte, as will be seen from the above Table, has to be treated by one of the following methods, according to whether nickel-copper alloys or nickel oxide and metallic nickel are desired:—

(1) *Production of Nickel-Copper Alloys.*—The matte is roasted to remove the sulphur, and directly reduced by charcoal or reducing gases.

(2) To manufacture nickel oxide the copper must be first removed from the matte. This is satisfactorily accomplished in the American practice by the Orford process or American sulphide process before described. If metallic nickel is desired, the nickel oxide is reduced by direct melting and reduction.

It may be mentioned that the refining of the molten matte by a blast of air was first suggested by Gibb and Gelstharp (British Patent No. 874 of 1870), and was subsequently made practical by Pierre Manhès, of Lyons, France. It may be also mentioned that Gossage in 1856 "proposed" to treat sulphurous ores by "currents of atmospheric air which are forced up and through the melted mass."

About 90 per cent. of the Bessemer matte is worked up into the nickel oxide for the manufacture of nickel steel, and about 7 per cent. converted into the pure metallic nickel.

*Ordinary Wet Process.*—The ordinary wet process is given in the Table on the following page.

*Bessemerizing Nickel Matte.*—A Paper of considerable interest was read before the American Society of Chemical Industry (1896) by Mr. H. W. Edwards, who was for several years in charge of the nickel-smelting plant in Sudbury, consisting of two blast-furnaces and a set of converters (Manhès modification).

The lining of the converters is the principal point upon which the economical success of the operation depends. Upon the lining depends the efficient supply of silica to aid in the formation of a silicate of iron slag. A large number of Canadian clays and quarries were tried, also basic lining, but the latter were not very successful, as the length of the blow was too much increased, thereby reducing the capacity of the plant as well as increasing the cost.

The normal charges required about 50 minutes' blowing, with a pressure of air

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| Materials. | Reactions. | Products. |
|---|---|---|
| | *Stage I.—Solution.* | |
| 1. The powdered calcined ore, speiss or matte.<br>2. HCl.<br>3. A jet of steam. | The acid dissolves out the soluble metals from the gangue and much ferric oxide. | 1. Gangue and ferric oxide, which go to waste.<br>2. A mixed chloride solution, which goes to the next stage. |
| | *Stage II.—Removal of Iron and Arsenic.* | |
| 1. Solution from the first stage.<br>2. Chloride of lime.<br>3. Milk of lime.<br>4. A jet of steam. | Any acid and ferrous iron present are peroxidized and precipitated. | 1. Ferric hydrate and iron arsenate, which go to waste.<br>2. A mixed chloride solution, which goes to the next stage. |
| | *Stage III.—Removal of Copper.* | |
| 1. The solution from the second stage.<br>2. HCl.<br>3. $H_2S$.<br>4. A jet of steam. | The copper is precipitated in the form of a sulphide. | 1. Copper sulphide available for the production of Cu.<br>2. A solution of Ni and Co chlorides which go to the next stage. |
| | *Stage IV.—Removal of Cobalt.* | |
| 1. The solution from the third stage.<br>2. Chloride of lime.<br>3. Milk of lime.<br>4. A jet of steam. | 1. The excess of $H_2S$ is boiled off.<br>2. Excess of acid is neutralized.<br>3. The cobalt is peroxidized and precipitated. | 1. Cobalt oxide which goes into the market.<br>2. A solution of nickel chloride. |
| | *Stage V.—Production of Metallic Nickel.*[1] | |
| 1. The solution from the fourth stage.<br>2. Milk of lime.<br>3. Charcoal, flour or other carbonaceous substances.<br>4. Fuel. | 1. Hydrate is precipitated.<br>2. The dried hydrate is made into a paste with flour and baked.<br>3. The baked mass (broken into fragments and strongly heated) parts with its C and O and becomes metallic. | 1. Gases which escape.<br>2. Metallic "grain nickel," which goes into the market. |

NOTE.—If the original ore contains arsenic, copper, cobalt, or manganese, these elements will also be found in the final metallic product, as the above depicted process is incapable of effectually removing them.

[1] The nickel thus obtained is commercially pure.

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commencing at 5 lbs. per square inch and reaching 7 lbs. The appearance of the flame is but very little guide, this being judged from the diminution of temperature and the character of the ejections.

*Total Production of Nickel.*—The world's production of nickel in tons is as follows:—

| — | New Caledonia. | Canada.[1] | United States. | Norway. | Sweden. | Total. |
|---|---|---|---|---|---|---|
| 1889 | 1381 | 309 | 98 | 88 | .. | 1876 |
| 1890 | 1633 | 651 | 90 | 70 | 8 | 2452 |
| 1891 | 2449 | 2098 | 54 | 91 | 12 | 4704 |
| 1892 | 1244 | 1888 | 43 | 97 | .. | 3272 |
| 1893 | 2045 | 1811 | 11 | 90 | .. | 3957 |
| 1894 | .. | 2225 | .. | 90 | .. | .. |
| 1895 | 2035 | 1763 | .. | .. | .. | 3798 |
| 1896 | 2972 | 1541 | .. | 90 | .. | 4603 |
| 1897 | .. | 1999 | .. | .. | .. | .. |
| 1898 | .. | 2463 | .. | .. | .. | .. |

Finally, as regards production of nickel in this country, a very large output is made by the La Société Anonyme le Nickel at their Erdington Works in Birmingham.[2] The ore is received and smelted at their Kirkintilloch Works near Glasgow, where it is refined into matte, which is then transferred to the Erdington Works, made into oxide, and from the oxide into refined nickel.

Although the information previously given refers to the Canadian ores, it may be mentioned that the New Caledonian nickel even went to America; but the tariff there has now led to the Sudbury ores being almost entirely used.

These statistics, which are taken principally from the well-known work, Rothwell's "Mineral Industry," for several years, not only include the metal, but its production also in the form of oxides and sulphides. For example, in 1896, the metallic nickel produced amounted to about 900 tons, valued at rates varying from 1s. 2d. per lb. to 1s. 6d. per pound.[3]

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[1] By far the greater proportion of the finished or fine nickel is produced by the Orford Copper Company at their Bayonne works, New Jersey, U.S.A., although made from Canadian ore or matte. Strictly speaking, therefore, the figures given under "Canada" have to be considered in connection with American production.

[2] The methods adopted by the well-known French specialists in the manufacture of nickel, Messrs. Christofle and Bouilbet, are given in an excellent article on the metal by Mr. Campredon in his recently published and important work, "Guide Pratique du Chimiste Metallurgique."

[3] The last report of the Ontario Mines Bureau states that for 1897 (12 months) and 1898 (9 months) the value of the nickel products there were respectively:—Ore smelted, 96,000 tons and 85,000 tons; nickel in matte, 1,990 tons and 1,830 tons; value of nickel, £72,000 and £68,000.

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The Canadian output, according to the Geological Survey, is valued as follows :—

| | £ | |
|---|---|---|
| 1890 | 186,000 | |
| 1891 | 551,000 | |
| 1892 | 279,000 | |
| 1893 | 414,000 | |
| 1894 | 374,000 | |
| 1895 | 272,000 | |
| 1896 | 231,000 | |
| 1897 | 200,000 | approximate nickel value. |
| | 80,000 | approximate copper value. |
| | 280,000 | |

In Canada the matte is taken at 13 cents per lb. at the mine.
In New Caledonia the output of ore has been :—

| —— | Production. | Exports. | Average value. |
|---|---|---|---|
| | Tons. | Tons. | |
| 1892 | 83,000 ore | .. | $14 per ton. |
| 1893 | 69,000 „ | 45,000 | .. |
| 1894 | 61,000 „ | 40,000 | .. |
| .. .. | 6 matte | .. | $700 per ton. |

It is stated [1] that, in 1896, 372,54 tons of nickel ore were exported from New Caledonia, 15,000 tons going to France, and 22,000 tons to Germany, valued at £81,000.

In 1897 the Sudbury output of ore was equivalent to a production of 1,800 tons of fine nickel, and 2,400 tons of fine copper, the respective values being approximately £200,000 and £96,000.

In view of the discussion now taking place in Canada on the subject of refining their nickel matte within the Dominion, and even including the ambitious project of manufacturing nickel steel, it is desirable to consider the exact position of the industry, and its position in respect to the American refiners. The control of refining nickel matte is largely held by the Orford Copper Company, of Constable Hook, near Bayonne, N.J., who export the greater part of their product to Europe.

In the year 1896 a total weight of between 1,600 and 1,700 tons of refined nickel was produced from Canadian ores. A total of 1,200 tons, or 75 per cent. of this production was exported to Europe, the United States using 420 tons, chiefly for armour in connection with the Government battle-ships.

In 1897 the output and proportions were nearly the same. The American refiners produced 1,770 tons, the whole of this, with the exception of 10 tons, being from the Canadian Sudbury ores. About 1,340 tons were exported, the balance, 430 tons, being used in the States. As previously mentioned, there has

[1] *Engineering and Mining Journal*, September 4th, 1897.

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been a recent movement in Canada to smelt and refine their own ores. In the last annual report of the Ontario Bureau of Mines, it is stated that strong attempts are being made to develop this industry, and it is hoped for the sake of colonial advancement that they will be successful.[1] As showing the important character of the smelting and refining operations, giving employment to large numbers of workmen, it may be mentioned, that if the labour cost of raising a certain quantity of nickel ore and reducing it to matte is taken at, say, £6,000 per month, the cost of extracting the metal contents is £20,000 per month. It would seem natural that the more expensive, and probably more profitable, part of the industry, should be carried on in the country which supplies the raw material.

*Production of Nickel by Electrolysis.*—The Balbach Smelting and Refining Company, of Newark, N.J., are successfully refining crude nickel. They take Orford anodes containing about 95 per cent. nickel, 0·55 per cent. copper, 0·75 per cent. iron, 0·45 per cent. carbon, and 3 per cent. sulphur (added to facilitate casting), and the metal which is deposited on the cathodes, beyond containing about 0·02 per cent. each sulphur and arsenic, is exceedingly pure. About 1,000 lbs. of this metal are produced daily in plates of $\frac{3}{8}$-inch thickness at the Balbach Works. The electro-deposited metal is exceedingly tough and stiff; plates of it can be punched or hammered without breaking or cracking. It is claimed by the users of the smelting process that they can obtain metal of 99·2 per cent. to 99·5 per cent. purity, and at much less expense than by the method just described.

*Mond Process of Nickel Extraction.*—Dr. Ludwig Mond has introduced a very interesting method of preparing nickel, though so far it has not been used on any large commercial scale.[2] About 20 tons to 25 tons of the metal have been produced, but the process is not believed to be now in operation. His valuable papers on the subject have appeared in the Journal of the Society of Chemical Industry (Nov. 30, 1895, p, 945). This method has a point of special interest, namely, that whilst it is usually very difficult to separate nickel and cobalt, the cobalt does not form a carbonyl. The specific gravity of nickel carbonyl ($Ni\ CO_4$) is 1·3185, its boiling point 43° C.[3]

An interesting Paper on "Volatile Compounds containing Nickel and Iron," was given by Mr. C. F. Townsend, F.C.S., in "Engineering" of 18th March, 1892. Reference may be made to it by those interested in this particular aspect of the question.

*Electrical Furnace Methods of Producing Nickel.*—In Mr. Moissan's important work, "Le four Electrique," it is stated that nickel and cobalt oxides are

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[1] This matter is being further followed, the Toronto Board of Trade, in a report presented and adopted in April, 1898 (fully detailed in *Iron Age* of May 5th, 1898), strongly recommending steps to be taken to assist the complete manufacture of nickel in Canada, instead of merely producing nickel matte and exporting it.

[2] An account of nickel steel made by the Author with ordinary Thompson nickel (produced from Canadian ores) and Mond nickel is given in Part I, p. 5.

[3] The Mond process has recently been described by Sir William Roberts-Austen, Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 29. Nickel-carbonyl deposits its nickel at low temperature (under 300° C.) upon shot of ordinary nickel; this is repeated until the coatings amount to as many as nine or ten. Thus 4 tons of shot grow to 15 tons or 16 tons.

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reduced with rapidity by carbon in the electric furnace. There have been obtained under these conditions cast metals (fontes) which contain :—

| — | Nickel. | Total Carbon. |
|---|---|---|
| | Per cent. | Per cent. |
| No. 1 . . . . . | 86·10 | 13·47 |
| No. 2 . . . . . | 87·62 | 11·90 |
| No. 3 . . . . . | 94·40 | 6·19 |

At the same time was obtained with manganese an alloy of 85 per cent. Mn, and 14·59 per cent. carbon.

It would be interesting to know whether, under similar conditions, iron could be made to absorb such high percentages of carbon.

*Cost of Nickel.*—A brief reference may be made to the cost of producing nickel, naturally an important point to the user. Still, whilst nickel possesses excellent qualities, the ordinary buyer of iron and steel products hesitates considerably to give the higher price for special products. The addition of nickel in itself is necessarily causing considerable increase in cost. For the manufacture of armour and other special products, special qualities are the chief object, price, a secondary one, and, in this case, little consideration need be given.

It is generally considered that as nickel costs 1*s.* 2*d.* per lb., the extra cost of a 1 per cent. nickel-iron alloy should be about £1 3*s.* per ton. But, as will be seen from Part II, "nickel steel" is a wide term covering a large number of special alloys, many of them very costly. Besides, even in the less costly percentages, from the rough to the finished article the gross waste is large, very seldom less than 50 per cent. The alloy or combination has to be made in a different manner to that of ordinary steel; special steels cannot be rushed through their manufacture like the ordinary steel of commerce.

The steel maker naturally looks for assistance in reducing the first cost to the producer of the metal itself—nickel. Even the present reduced rate is high, namely, about 1*s.* 2*d.* per lb. The supplies of ore are almost inexhaustible; the methods of production are now much simplified, therefore the more cheaply the metal is offered the larger will be its field. There is no reason to doubt that, in case of a larger demand for the metal, the producer would eventually be able to considerably reduce the present selling price.

It may be mentioned that the Canadian Copper Company, whose original property is stated to have cost about £120,000, has now a capital of £500,000, and has paid for some time past 8 per cent. dividend on this capitalization. The works are at Copper Cliff, 4 miles from Sudbury (Ont.). In 1891–2 there were works at Cleveland under the direction of Mr. Garnier, but he could do nothing with Canadian ores, and since that time it has been used solely as an experimental station.

The Orford Copper Company is a separate organization, but the two companies work in harmony, the Orford Company taking practically the whole output of the Canadian Copper Company. Their refining is carried out at their Constable Hook Works, N.J.

The Canadian Copper Company crushes about 400 tons per day. Every credit is due to them for their pioneer work, and the rapid development they have made.

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## APPENDIX II.

### Properties of Unforged Nickel and Iron Alloys, that is, in their Cast Condition.

From the report of the "Special Committee Appointed for the Study of Iron Alloys" (presided over by Dr. Wedding, Berlin, and the reports made by Professor M. Rudeloff), given in the "Transactions of the Society for the Promotion of Industry, 1896, 1897," the following results are obtained. As no satisfactory account has yet appeared in England regarding these experiments, the Author gives the following full details.

The test-bars for the experiments were cut from ingots as cast, without any previous forging of the latter. In this respect, therefore, this research is of quite a different nature to that carried out by the Author.

The analysis of the ingots made by Doctors Knorre and Pufahl are given in the following Table:—

| Ingot No. | Intended percentage of Ni. | Fe. | Ni. | Co. | Cu. | Mn. | Mg. | Al. | Si. | S. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| 1—3 | ..[1] | 99·59 | 0·05 | 0·01 | 0·06 | 0·05 | 0·01 | 0·06 | 0·04 | 0·02 |
| 4—5 | 0·5 | 98·98 | 0·76 | 0·04 | 0·07 | 0·06 | 0·01 | 0·02 | 0·03 | 0·02 |
| 7—9 | 1·0 | 98·75 | 1·01 | 0·02 | 0·04 | 0·05 | 0·02 | 0·05 | 0·04 | 0·02 |
| 10—12 | 2·0 | 97·72 | 2·05 | 0·05 | 0·06 | 0·03 | 0·02 | 0·03 | 0·06 | 0·02 |
| 13—14 | 3·0 | 96·73 | 3·00 | 0·06 | 0·07 | 0·03 | 0·03 | 0·03 | 0·06 | 0·02 |
| 16—18 | 4·0 | 95·81 | 3·98 | 0·07 | 0·06 | 0·02 | 0·02 | 0·04 | 0·05 | 0·02 |
| 19—21 | 5·0 | 94·81 | 4·92 | 0·09 | 0·07 | trace | 0·02 | 0·05 | 0·05 | 0·02 |
| 22—24 | 8·0 | 91·89 | 7·84 | 0·11 | 0·06 | „ | 0·02 | 0·07 | 0·04 | 0·02 |
| 25—27 | 16·0 | 84·12 | 15·59 | 0·13 | 0·06 | .. | 0·01 | 0·07 | 0·05 | 0·02 |
| 28—30 | 30·0 | 60·74 | 29·77 | 0·28 | 0·05 | 0·02 | trace | 0·03 | 0·05 | 0·02 |
| 31—33 | 60·0 | 39·69 | 59·60 | 0·49 | 0·10 | .. | 0·07 | .. | 0·06 | 0·01 |
| 34—36 | 95·0 | 5·15 | 93·68 | 0·98 | 0·08 | trace | 0·09 | .. | 0·08 | trace |
| 37—39 | 100·0 | 0·33 | 98·39 | 1·03 | 0·07 | .. | 0·12 | .. | 0·10 | „ |

Analytical skill seems to have developed in great detail, but unfortunately no reference is made to the most important of all the elements, viz., carbon. It is difficult to believe that none was present. Perhaps if the Author's Paper comes under the Committee's notice they will supply this information, as completing a very valuable research. The Author also deals with this point later in this Appendix.

[1] The percentage of manganese in ingot No. 1 averaged 0·225 per cent., that in ingots Nos. 2 and 3 0·345 per cent. only; the Committee stated that this difference made itself felt in the mechanical properties of the material.

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The average results of the tensile tests on these cast nickel-iron alloys were as follows:—

| Ingot No. | Approx. percentage of Ni.[1] | Stress in Kilos. per Square Millimetre at:[2] | | | Modulus of Elasticity. Kilos. per Sq. Millimetre. | Elongation at fracture on: | | Ratio between per cent. Stresses. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Limit of Proportionality. $\sigma_p$ | Yield point. $\sigma_S$ | Breaking Load. $\sigma_B$ | $\Sigma$ | 25 Millimetres. $\delta_{25}$ | 50 Millimetres. $\delta_{50}$ | $\frac{\sigma_p}{\sigma_S}$ | $\frac{\sigma_p}{\sigma_B}$ | $\frac{\sigma_S}{\sigma_B}$ |
| | Per cent. | | | | | | | Per cent. | Per cent. | Per cent. |
| 1—3* | 0 | 6·0 | 14·6 | 32·4 | 22525 | 36·8 | 29·7 | 0·41 | 0·19 | 0·45 |
| 4—5 | 0·76 | 6·2 | 15·9 | 32·1 | 20790 | 25·1 | 20·6 | 0·39 | 0·19 | 0·50 |
| 7—9 | 1·0 | 7·2 | 16·6 | 33·7 | 21050 | 31·8 | 26·4 | 0·43 | 0·21 | 0·49 |
| 10—12 | 2·0 | 10·2 | 20·2 | 37·0 | 20710 | 26·1 | 22·7 | 0·50 | 0·28 | 0·55 |
| 13—15 | 3·0 | 16·1 | 24·0 | 40·6 | 20070 | 23·4 | 20·1 | 0·67 | 0·40 | 0·59 |
| 16—18 | 4·0 | 16·6 | 26·9 | 40·6 | 20170 | 20·1 | 17·6 | 0·62 | 0·41 | 0·66 |
| 19—21 | 5·0 | 19·6 | 32·5 | 44·6 | 19930 | 12·9 | 10·8 | 0·60 | 0·44 | 0·73 |
| 22—24 | 8·0 | 22·8 | 44·2 | 56·2 | 19280 | 11·1 | 9·6 | 0·52 | 0·41 | 0·79 |
| 25—27 | 16·0 | 16·0 | .. | 41·0 | 16200 | 0·9 | 0·6 | .. | 0·39 | .. |
| 28—30 | 30·0 | 6·3 | 12·5 | 9·9 | 12300 | 2·8 | 2·2 | 0·50 | 0·64 | 1·36 |
| 31—33 | 60·0 | 6·0 | 12·5 | 37·8 | 14490 | 37·9 | 36·1 | 0·48 | 0·16 | 0·33 |
| 35—36 | 94·0 | 4·1 | 10·8 | 33·2 | 17590 | 20·1 | 19·0 | 0·38 | 0·12 | 0·33 |
| 37—39 | 98·5 | 3·6 | 9·1 | 30·5 | 16870 | 18·2 | 17·1 | 0·40 | 0·12 | 0·30 |

| * Ingot. | Mn | $\sigma_p$ | $\sigma_S$ | $\sigma_B$ | $\Sigma$ | $\delta_{25}$ | $\delta_{50}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0·225 | 8·1 | 17·5 | 36·9 | 20630 | 29·3 | 24.3 |
| 2—3 | 0·045 | 6·0 | 14·6 | 32·4 | 22525 | 34·3 | 29·7 |

The influence of the nickel 'present is still more clearly shown by the following summary, in which all values of equal denomination are referred to those for pure iron, which is itself taken as 100[3]:—

| Mean percentage of Ni. | Loads. | | | Elongation on a length of 25 Millimetres each from the points of fracture. |
|---|---|---|---|---|
| | Limit of proportionality. | Yield Point. | Ultimate breaking strength. | |
| 0·05 | 100 | 100 | 100 | 100 |
| 8·0 | 380 | 303 | 173 | 30 |
| 16·0 | 267 | 280 | 126 | 2 |
| 30·0 | 105 | 86 | 31 | 8 |
| 60·0 | 100 | 86 | 117 | 103 |
| 98·0 | 60 | 62 | 94 | 50 |

The appearance of the fractured surface led the Committee to conclude that cast nickel-iron alloys containing about 0·5 per cent. Ni tend to form a material

[1] The exact analysis obtained is given in the first Table.

[2] To convert approximately the results of the various stresses, whether limits of proportionality, yield point or breaking loads, from kilos. per square millimetre into tons per square inch, multiply the former by the factor 0·6 (0·625 exactly).

[3] The Committee do not state whether the material was tested in the unannealed or annealed condition; this is, of course, an important point.

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with a fibrous fracture, but as soon as the percentage of nickel attains 1 per cent. only, the material becomes compact—that is, crystalline and granular, and the tensile test bars up to 3 per cent. Ni, are pronouncedly granular. On a still further increase of the percentage, the cast metal in the first place assumes a less granular fracture, and, finally, a pronounced acicular character. An exception in this series is constituted by the ingots with 60 per cent. Ni, which again present a predominantly coarse granular texture, and more especially at 30 per cent. Ni the cast metal has a tendency to show signs of oxidation upon being fractured.

In proportion as the percentage of nickel increases, up to about 16 per cent. Ni the resistance to compression increases, and consequently a decrease in liability to change of form, both variations taking place almost at the same ratio at which the percentage of nickel increases. On still further increasing the percentage of nickel (up to 94 per cent.) the resistance to compression at first decreases rapidly (up to 30 per cent. Ni), then slowly, but at about 98 per cent. Ni it again increases a little. On the other hand, the capability of deformation under pressure increases between 16 per cent. and 30 per cent. Ni, then decreases up to 60 per cent. Ni, and finally, at 98 per cent. Ni, it again attains the same value as found for the 30 per cent. alloy.

In the "setting up" noticed, the capability of deformation decreases as the percentage of nickel in the material increases, up to 16 per cent. Ni. At 30 per cent. Ni it attains approximately the same value as for the material cast without any addition of Ni; at 60 per cent. Ni it again is a little lower, and finally, in the 98 per cent. nickel alloys it is again as great as in the 30 per cent.

The foregoing results are generally of similar nature to those obtained by the Author.

The influence of the percentage of nickel on the resistance to shearing will be seen from the following list:—

| Ingot No. | Average percentage of Ni. | Resistance to Shearing. | Ingot No. | Average percentage of Ni. | Resistance to Shearing. | Ingot No. | Average percentage of Ni. | Resistance to Shearing. |
|---|---|---|---|---|---|---|---|---|
| | | Kilos per sq. mm. | | | Kilos per sq. mm. | | | Kilos per sq. mm. |
| 1—3 | 0·05 | 26·6 | 16—18 | 3·98 | 34·0 | 28—30 | 29·78 | 35·4 |
| 4 | 0·56 | 25·9 | 19—21 | 4·92 | 36·6 | 31—33 | 59·60 | 37·9 |
| 7—9 | 0·10 | 28·4 | 22—24 | 7·84 | 43·5 | 35—36 | 93·52 | 35·7 |
| 10—12 | 2·06 | 30·5 | 25—27 | 15·60 | 67·7 | 37—39 | 98·39 | 34·7 |
| 13—15 | 3·01 | 33·3 | | | | | | |

*The co-efficient of expansion* decreased, as the percentage of nickel increased (up to about 16 per cent. Ni), but was greater with the 98 per cent. Ni specimen than in pure iron, as the following figures will show:—

| Rod No. | From Ingot No. | Ni. | Expansion in Micromillimetres per metre and 1° C. | Difference as compared with pure iron. |
|---|---|---|---|---|
| | | Per cent. | | Per cent. |
| 1 | 3 | 0·0 | $11·56 \pm 0·02 + (0·0056 \pm 0·0015)\,t$ | |
| 2 | 16 | 4·0 | $10·90 \pm 0·02 + (0·0056 \pm 0·0015)\,t$ | 5·7 |
| 3 | 27 | 16·0 | $10·30 \pm 0·05 + (0·0056 \pm 0·0015)\,t$ | 10·9 |
| 4 | 38 | 10·0 | $12·61 \pm 0·07 + (0·0056 \pm 0·0015)\,t$ | 0·1 |

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The following results are given as showing the exceedingly thorough manner in which this series of experiments were carried out by Dr. Wedding's Committee.

In forging and rolling, the alloys behaved as follows:—

| Ingot No. | Ni. | Section before Forging. | Results of Forging. | | |
|---|---|---|---|---|---|
| | | | Temperature. | | Nature exhibited by the Material. |
| | | | Before. | After. | |
| | Per cent. | | °C. | °C. | |
| 1 | 0·0 | | 680 | 590 | Very malleable. |
| 2 | | | 630 | 570 | Malleable, forging lasted 150 seconds. |
| 3 | | | .. | 630 | Malleable, fissured, in part forged. |
| 4 | 0·5 | Full | 650 | 600 | Very malleable. |
| 5 | | .. | 630 | 560 | Malleable, forging lasted 95 seconds. |
| 7 | 1·0 | .. | 620 | 570 | Very malleable. |
| 8 | | .. | 660 | 530 | Malleable, forging lasted 115 seconds. |
| 9 | | .. | 710 | 630 | Difficult to forge, but free from fissures. |
| 10 | 2·0 | As in 1 | 620 | 580 | Very malleable. |
| 11 | | .. | 620 | 580 | Difficult to forge, but free from fissures. |
| 12 | | Full | 750 | 600 | Malleable. |
| 13 | 3·0 | .. | 760 | 670 | Fissured in some places. |
| 14 | | .. | 710 | 540 | Solid,* but free from fissures; forging lasted 125 seconds. |
| 15 | | .. | 610 | 580 | Malleable. |
| 16 | 4·0 | As at 1 | 700 | 650 | Split at the feed-head end. |
| 17 | | Full | 680 | 580 | Solid, but free from fissures; forging lasted 100 seconds. |
| 18 | | .. | 740 | 610 | Malleable. |
| 19 | 5·0 | As at 1 | 730 | 580 | At 780·580° C. very well malleable; split at feed-head end. |
| 20 | | .. | 660 | 560 | Very soft; free from fissures; forging lasted 120 seconds. |
| 21 | | Full | 710 | 620 | Malleable. |
| 22 | 8·0 | .. | 680 | 580 | At both temperatures malleable, also at 450° C.; slight fissures. |
| 23 | | .. | 640 | 580 | Very solid (rigid) but malleable; forging lasted 100 seconds. |
| 24 | | .. | 660 | 630 | Very solid but malleable. |
| 25 | 16·0 | As at 1 | 760 | 580 | Very malleable. |
| 27 | | .. | 770 | 720 | Malleable. |

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| Ingot No. | Ni. | Section before Forging. | Results of Forging—*continued.* Temperature. Before. | After. | Nature exhibited by the Material. |
|---|---|---|---|---|---|
| | Per cent. | | °C. | °C. | |
| 28 | 30·0 | Full | 660 | 580 | Very red-short; not malleable, not even at higher temperatures, over 640° after forging. |
| 29 | | .. | 780 | .. | Completely fell to pieces, into three parts; even at 660° the same. |
| 30 | | .. | 500 | 360 | Completely fell to pieces. |
| 31 | 60·0 | As at 1 | 660 | 540 | Strongly fissured. |
| 32 | | .. | 700 | 650 | Fissured at third forging (at which the temperatures were 700° and 630°). |
| 33 | | Full | 660 | 580 | Easily forged, but fissured, especially at higher temperatures (over 740°). |
| 35 | 95·0 | .. | 800 | 720 | A fissure at ⅓ of its length. |
| 36 | | .. | 700 | 650 | Well malleable. |
| 37 | 100 | .. | 750 | 630 | Strongly fissured, longitudinal jumping without effect. |
| 38 | | .. | 890 | 730 | Red-short, even at 730° C. initial temperature. |
| 39 | | .. | 710 | 620 | Less red-short than 38. |

Results of Rolling—

| Ingot No. | (*a*) Into a Round Bar. Temperature. Before. | After. | Time occupied by work of Rolling. | Nature exhibited by the Material. | (*b*) Of the Round Bar into a Flat Bar. Temperature of Furnace— Before taking out the Iron. | On Stoking (? drawing the Fire). | Nature exhibited by the Material. |
|---|---|---|---|---|---|---|---|
| | °C. | °C. | Secs. | | | | |
| 1 | .. | .. | .. | Free from fissures | 1,140 | 1,115 | Free from fissures. |
| 2 | 700 | 560 | 95 | Burr formed in places | 1,140 | 1,115 | ,, ,, |
| 3 | .. | .. | .. | ,, ,, | .. | .. | .. .. |
| 4 | .. | .. | .. | Free from fissures | 1140 | 1115 | Free from fissures. |
| 5 | 720 | 500 | 85 | Ditto, with formation of burr | 1140 | 1115 | Fissured on one of the narrow sides. |
| 7 | .. | .. | .. | Fallen to pieces | .. | .. | .. |
| 8 | .. | .. | .. | Free from fissures Scaly in places | .. | .. | .. |
| 9 | 700 | 530 | 90 | Fissured | 1140 | 1115 | Both narrow sides fissured |
| 10 | .. | .. | .. | Fissured | 1140 | 1150 | Free from fissures. |
| 11 | 720 | 550 | 98 | Free from fissures | 1140 | 1150 | ,, ,, |
| 12 | .. | .. | .. | Slightly fissured | .. | .. | .. |

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| Ingot. | Results of Rolling—*continued*. (a) Into a Round Bar. Temperature. Before. | After. | Time occupied by work of Rolling. | Nature exhibited by the Material. | (b) Of the Round Bar into a Flat Bar. Temperature of Furnace— Before taking out the Iron. | On Making (Drawing the Fire). | Nature exhibited by the Material. |
|---|---|---|---|---|---|---|---|
| | °C. | °C. | Secs. | | | | |
| 13 | .. | .. | .. | Free from fissures | 1,140 | 1,150 | Narrow sides fissured. |
| 14 | 720 | 570 | 80 | Ditto | 1,140 | 1,150 | Free from fissures. |
| 15 | .. | .. | .. | Ditto | .. | .. | .. .. |
| 16 | .. | .. | .. | Slight fissures | .. | .. | .. .. |
| 17 | .. | .. | .. | Free from fissures | 1,140 | 1,115 | Free from fissures. |
| 18 | 800 | 510 | 88 | Slight fissures | 1,140 | 1,115 | One of narrow sides fissured. |
| 19 | .. | .. | .. | Fissured | .. | .. | .. |
| 20 | .. | .. | .. | Ditto | 1,140 | 1,115 | Narrow sides fissured. |
| 21 | 700 | 490 | 105 | Free from fissures | 1,140 | 1,115 | Free from fissures. |
| 22 | .. | .. | .. | Fallen to pieces | .. | .. | .. |
| 23 | .. | .. | .. | Slight fissures | 1,140 | 1,115 | .. |
| 24 | 730 | 500 | 102 | Ditto | 1,140 | 1,115 | .. |
| 25 | .. | .. | .. | Ditto | 1,140 | 1,115 | Fissured. |
| 27 | 750 | 750 | 90 | Very strongly fissured | 1,140 | 1,115 | Strongly fissured. |
| 28 | .. | .. | .. | Broken; fallen to pieces | .. | .. | .. |
| 29 | .. | .. | .. | Ditto | .. | .. | .. |
| 30 | .. | .. | .. | Not rollable | .. | .. | .. |
| 31 | .. | .. | .. | Strongly fissured | .. | .. | .. |
| 32 | .. | .. | .. | Very strongly fissured | 1,140 | 1,115 | Strongly fissured. |
| 33 | 760 | 520 | 98 | Fissured | 1,200 | 1,150 | Fissured. |
| 35 | .. | .. | .. | Strongly fissured | 1,200 | 1,150 | Fissured. |
| 36 | 790 | 550 | 92 | Ditto | 1,140 | 1,115 | Narrow sides, strongly fissured. |
| 37 | .. | .. | .. | Very strongly fissured . . . . | .. | .. | .. |
| 38 | .. | .. | .. | Ditto | 1,200 | 1,150 | Fine fissures. |
| 39 | 820 | 540 | 95 | Ditto | 1,200 | 1,150 | Fissured. |

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The Author considers that a general comparison of these results on the cast nickel-iron alloys shows, as is usually found to be the case, that the difference between cast and forged material is to the disadvantage of the former—in other words, that rolling and forging has considerably improved the results obtained, whether as regards tensile strength or ductility.

Somewhat unfortunately, however, there is no reference or analysis regarding the carbon present. It would have been much more satisfactory to have information upon this point, as, no matter how carefully the specimens were prepared, it is almost certain that this element could not be entirely absent. If they were fused in a crucible, it is almost certain that a percentage of carbon must have been taken up by the molten alloy. No matter how small, its influence would be much greater than that of any of the other elements determined with such care. Owing to the powerful influence of this element, even $\frac{1}{10}$ per cent. would have a considerable effect, as the author found in his specimens, containing an average percentage of 0·17 per cent. carbon. It appears that $\frac{1}{10}$ per cent. of aluminium was added to the various specimens in which iron was present, that is, to the whole of the series except the last one, which was pure nickel, and in this case 0·05 per cent. magnesium was added.

Further information upon the above points, especially regarding carbon percentages, would be very useful, and make a most interesting and exhaustive set of experiments thoroughly complete.

The series is also somewhat deficient in specimens at the specially critical points. The nickel percentages aimed at after exceeding 5 per cent. were as follows: 8 per cent., 16 per cent., and 30 per cent. As will be seen from the Author's series, some of the most interesting nickel-iron alloys are met with between the zone of 8 per cent. to 16 per cent., also between 16 per cent. to 30 per cent. The Author's specimens cover these zones by 9·51 per cent. (specimen H), 11·39 per cent. (I), 19·64 per cent. (K), and 24·51 per cent. (L). His specimens do not go beyond 50 per cent., as the material does not then present any interest to an iron and steel metallurgist.

The whole research and the complete manner in which it was carried out are but another proof of the great desirability of this country establishing a similar National Physical Laboratory to the Reichsanstalt in Berlin, where the above experiments were carried out. There are but few manufacturers who have either the necessary facilities or the time to take up such complete researches of this nature.

As one who has worked for many years in this special field, the Author offers his hearty congratulations as to the results of the work of the Berlin Committee, presided over by the eminent scientist and metallurgist Dr. H. Wedding, a Bessemer Gold-Medallist, by whose labours German metallurgists have largely benefited.



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APPENDIX III.—TABLE I.—GENERAL TABLE, SHOWING ANALYSIS, SPECIFIC GRAVITY, EL
QUALITIES OF UNANNEALED AND ANNEALED NICKEL-

| Series and Mark referred to in Paper. | Analysis per cent. | | | | | | Calculated percentage of Nickel. | Specific Gravity in Cast Condition. | Limit of Elasticity in Tons per Square Inch. | | Amount of Stretch in Inches at Elastic Limit. | | Breaking in Tons Square on Orig Are |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Carbon. | Silicon. | Sulphur. | Phosphorus. | Manganese. | Nickel. | | | Unannealed. | Annealed. | Unannealed. | Annealed. | Unannealed. |
| 1,287 A | 0·19 | 0·31 | 0·10 | 0·09 | 0·79 | 0·27 | 0·25 | 7·691 | 19·00 | .. | 0·0028 | .. | 31·50 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 20·00 | .. | 0·0023 | .. |
| 1,287 B | 0·14 | 0·20 | .. | .. | 0·75 | 0·51 | 0·50 | .. | 20·50 | .. | 0·0032 | .. | 30·00 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 21·50 | .. | 0·0038 | .. |
| 1,287 C | 0·13 | 0·23 | .. | .. | 0·72 | 0·95 | 1·00 | 7·785 | 25·50 | .. | 0·0043 | .. | 33·50 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 20·50 | .. | 0·0033 | .. |
| 1,287 D[1] | 0·14 | 0·21 | 0·08 | 0·07 | 0·72 | 1·92 | 2·00 | .. | 26·00 | .. | 0·0035 | .. | 34·50 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 22·00 | .. | 0·0040 | .. |
| 1,287 E | 0·19 | 0·20 | .. | .. | 0·65 | 3·82 | 4·00 | 7·777 | 28·00 | .. | 0·0055 | .. | 37·00 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 25·00 | .. | 0·0044 | .. |
| 1,287 F | 0·18 | 0·31 | .. | .. | 0·65 | 5·81 | 6·00 | .. | 28·50 | .. | 0·0041 | .. | 41·00 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 28·50 | .. | 0·0040 | .. |
| 1,287 G | 0·17 | 0·28 | 0·11 | 0·08 | 0·68 | 7·65 | 8·00 | 7·743 | 31·50 | .. | 0·0040 | .. | 49·50 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 30·50 | .. | 0·0053 | .. |

[1] Professor Arnold, for his Paper on "The Physical Influence of Elements on Iron specimen "D," but nickel only 1·51 per cent. It was also somewhat lower in carbon (0 the results obtained by him, viz.: Limit of elasticity, 22·45 tons; breaking load 26·8

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IT, BREAKING LOAD, ELONGATION, REDUCTION OF AREA, BENDING, WELDING, AND CORROSION OTS. (These results are plotted on Figs. 1 and 8, Plate 1.)

| Total ongation r cent. on inches. | | Reduction of Area per cent. | | Appearance of Fractured Test-Bar. | Bending Tests of Unannealed and Annealed Forged Bars $\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch thick. | | Welding Tests. | Corrosion Tests. | |
|---|---|---|---|---|---|---|---|---|---|
| nealed. | An-nealed. | Unan-nealed. | An-nealed. | | Unan-nealed. | An-nealed. | | Loss in Grains. | Loss per cent. |
| 60 .. | | 55·92 | .. | Dark granular; fibrous; silky at edges; several specks in body; cup fracture . . . . | Double, unbroken | Double, unbroken | Would not weld | .. | .. |
| .. | 37·05 | .. | 52·14 | „ „ | .. | .. | .. | .. | .. |
| 77 .. | | 61·98 | .. | Dark granular; fibrous; silky at edges; several specks in body; cup fracture . . . . | Double, unbroken | Double. unbroken | .. | .. | .. |
| . | 41·00 | .. | 63·66 | „ „ | .. | .. | .. | .. | .. |
| 10 .. | | 53·86 | .. | Dark granular; fibrous; silky at edges; several specks in body; very roaky; cup fracture . | Double, unbroken | Double, unbroken | .. | 2·003 | 3·23 |
| . | 41·75 | .. | 63 36 | „ „ | .. | .. | .. | .. | .. |
| 85 .. | | 55·22 | .. | Dark granular; fibrous; silky at edges; several specks in fracture; not cup fracture . . . | Double, unbroken | Double, unbroken | .. | .. | .. |
| .. | 36·26 | .. | 53·70 | Dark granular; little silky at edges; several specks in body; not cup fracture; rather more granular. | .. | .. | .. | .. | .. |
| 85 .. | | 54·20 | .. | Dark granular; fibrous; silky at ends: several specks in fracture . | 90 per cent., broken | Double, unbroken | .. | 1·611 | 2·95 |
| .. | 35·85 | .. | 55·56 | Dark granular; fibrous; silky at edges; several specks in body; badly roaked. | .. | .. | .. | .. | .. |
| 62 .. | | 40·22 | .. | Dark granular; fibrous; silky at edges . . . | Double, unbroken | Double, unbroken | Would not weld | .. | .. |
| . | 33·15 | .. | 51·62 | Dark granular; fibrous; silky at edges; slight cup fracture. | .. | .. | .. | .. | .. |
| 60 .. | | 42·70 | .. | Dark granular; fibrous; silky at edges . . . | 26°, broken | 89°, broken | .. | 1·581 | 2·7 |
| . | 26·05 | .. | 40·90 | „ „ | .. | .. | .. | .. | .. |

Steel Institute Journal, No. 1, 1894), produced a somewhat similar material to this t.), and manganese was practically absent (0·09 per cent.). It may be interesting to give ngation, 38·3 per cent.; reduction of area, 62 per cent.



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TABL

| Series and Mark referred to in Paper. | Analysis per cent.[2] | | | | | | Calculated percentage of Nickel. | Specific Gravity in Cast Condition. | Limit of Elasticity in Tons per Square Inch.[4] | | Amount of Stretch in Inches at Elastic Limit. | | Breaking in Tons Square on Orig Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Carbon. | Silicon. | Sulphur. | Phosphorus. | Manganese. | Nickel. | | | Unannealed. | Annealed. | Unannealed. | Annealed. | Unannealed. |
| 1,287 H | 0·16 | 0·20 | .. | .. | 0·86 | 9·51 | 10·00 | .. | 42·47 | .. | 0·0012 | .. | 85·50 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 32·50 | .. | 0·0040 | .. |
| 1,287 I | 0·18 | 0·22 | .. | .. | 0·93 | 11·39 | 12·00 | .. | 55·70 | .. | 0·0015 | .. | 94·00 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 45·50 | .. | 0·0016 | .. |
| 1,287 J[1] | 0·23 | 0·24 | 0·11 | 0·05 | 0·93 | 15·48 | 16·00 | 7·752 | 50·55 | .. | 0·0027 | .. | 94·00 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bar cracked | .. | .. | .. |
| 1,287 K | 0·19 | 0·27 | .. | .. | 0·93 | 19·64 | 20·00 | .. | 47·50 | .. | 0·0038 | .. | 91·00 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 45·00 | .. | 0·0060 | .. |
| 1,287 L | 0·16 | 0·30 | .. | .. | 1·00 | 24·51 | 25·00 | 7·810 | 32·5 | .. | .. | .. | 77·00 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 25·00 | .. | 0·0075 | .. |
| 1,287 M | 0·14 | 0·38 | .. | .. | 0·86 | 29·07 | 30·00 | 8·054 | 25·00 | .. | 0·0058 | .. | 38·50 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 16·00 | .. | 0·0057 | .. |
| 1,287 N | 0·16 | 0·31 | 0·08 | 0·06 | 1·08 | 49·65 | 50·00 | | No tests made on unannealed mate | | | | |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 15·00 | .. | 0·0080 | .. |

[1] Bar cracked in thread. The real tensile strength would probably not be less than that
[2] The original diameter of all tensile test-bars was 0·7979 inch, original area 0·50 inc
[4] In certain cases of the harder material the elastic limit could only be ascertained a

ensed.

| Total ngation cent. on inches. | | Red ction of Area per cent. | | Appearance of Fractured Test-Bar. | Bending Tests of Unannealed and Annealed Forged Bars ½ inch wide and ¼ inch thick. | | Welding Tests. | Corrosion Tests. | |
|---|---|---|---|---|---|---|---|---|---|
| | An- nealed. | Unan- nealed. | An- nealed. | | Unan- nealed. | An- nealed. | | Loss in Grains. | Loss per cent. |
| 32 | .. | 18·12 | .. | Dark granular; fibrous; silky at edges . . . | 28°, broken | 5°, broken | .. | .. | .. |
| . | 2·50 | .. | 1·98 | Very fine crystals; broken in radius. | .. | .. | .. | .. | .. |
| 85 | .. | 24·36 | .. | Dark granular; fibrous; silky at edges; several roaks in body . . . | 22°, broken | 8° | Would not weld | 1·390 | 2·60 |
| . | 11·80 | .. | 26·08 | Dark granular; fibrous; silky at edges; several cracks in body. | .. | .. | .. | .. | .. |
| 15 | .. | 2·48 | .. | Granular, fibrous, and silky at edges; bar very badly roaked, being almost divided into four distinct pieces | Not tested | Not tested | .. | .. | .. |
| . | 1·15 | .. | 0·74 | Very fine crystals; fibrous and silky at edges; bar very badly roaked, and almost divided into two pieces | .. | .. | .. | .. | .. |
| 90 | .. | 6·40 | .. | Granular, fibrous, and silky at edges; roaked in centre . . . . | 18°, broken | 17°, broken | .. | .. | .. |
| . | 5·67 | .. | 4·68 | Very fine crystals; fibrous and silky at edges; very much roaked in centre. | .. | .. | .. | .. | .. |
| 65 | .. | About 14·00 | .. | Very fine crystals; very badly roaked, being in four distinct pieces . | Not tested | Not tested | .. | .. | .. |
| . | 14·85 | .. | 8·56 | Granular, fibrous, and silky at edges; bar very badly roaked, being divided in two distinct pieces. | .. | .. | .. | .. | .. |
| 92 | .. | 44·02 | .. | Granular, fibrous, and silky; bar very badly roaked in centre . . | Double, unbroken | Double, unbroken | Would not weld | 0·759 | 1·34 |
| . | 48·35 | .. | 51·62 | Granular, fibrous, and silky at edges; several roaks in body. | .. | .. | .. | .. | |
| . | 49·05 | .. | 53·10 | .. .. Granular; fibrous; silky at edges; several roaks in body. | .. .. | .. .. | .. .. | .. .. | .. .. |

The drillings for analysis were all taken from ingot fractures as cast.
ngation measured on a length of 2 inches.
ely as shown.

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TABLE II.—BENDING TESTS OF CAST AND FORGED NICKEL-IRON ALLOYS IN THE UNANNEALED AND ANNEALED CONDITION.

These results are plotted on Figs. 2 and 3, Plate 1.

| Specimen Mark. | Analysis per cent. | | Cast. | | Forged. | |
|---|---|---|---|---|---|---|
| | C. | Ni. | Size of Bar 6 inches × 1 inch × $\frac{1}{16}$ inch. | | Size of Bar 4½ inches × $\frac{11}{16}$ inch × ¼ inch. | |
| | | | Unannealed—Bent to | Annealed—Bent to | Unannealed—Bent to | Annealed—Bent to |
| | | | ° | ° | ° | ° |
| A | 0·19 | 0·27 | 18, broken | 154, broken | Double, unbroken | Double, unbroken |
| B | 0·14 | 0·51 | 29 „ | 80 „ | „ „ | „ „ |
| C | 0·18 | 0·95 | 91 „ | 85 „ | „ „ | „ „ |
| D | 0·14 | 1·92 | 150 „ | Double „ | „ „ | „ „ |
| E | 0·19 | 3·82 | 24 „ | 100 „ | 90, broken | „ „ |
| F | 0·18 | 5·81 | 11 „ | 71 „ | Double, unbroken | „ „ |
| G | 0·17 | 7·65 | Nil „ | 41 „ | 26, broken | 89, broken |
| H | 0·16 | 9·51 | 2 „ | 8 „ | 28 „ | 5 „ |
| I | 0·18 | 11·39 | 3 „ | 9 „ | 22 „ | 3 „ |
| J | 0·23 | 15·48 | 2 „ | 11 „ | No test made | .. |
| K | 0·19 | 19·64 | 2 „ | 8 „ | 18, broken | 17, broken |
| L | 0·16 | 24·51 | 12 „ | 10 „ | No test made | .. |
| M | 0·14 | 29·07 | 163 „ | 64 „ | Double, unbroken | Double, unbroken |
| N | 0·16 | 49·65 | 53 „ | 19 „ | No test made | .. |

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TABLE III.—COMPARISON TABLE OF ELASTIC LIMIT, BREAKING LOAD, ELONGATION, REDUCTION OF AREA AND BENDING TESTS OF FORGED SILICON, ALUMINIUM, CHROMIUM AND NICKEL-IRON ALLOYS, ALL THE MATERIAL HAVING BEEN ANNEALED. TO THESE ARE ADDED COMPARISONS OF TUNGSTEN AND COPPER ALLOYS.

These results are plotted on Fig. 4, Plate 1.

| Steel. | C. | Si. | Al. | Cr. | Ni. | Limit of Elasticity in Tons per Square Inch. | Breaking Load in Tons per Square Inch. | Elongation per cent. on 2 Inches. | Reduction of Area per cent. | Breaking Test of Annealed Forged Sample. |
|---|---|---|---|---|---|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | | | | | |
| Silicon . A | 0·14 | 0·24 | .. | .. | .. | 15·17 | 25·00 | 37·55 | 60·74 | Double. |
| Aluminium A | 0·15 | .. | 0·38 | .. | .. | 20·00 | 26·00 | 40·35 | 60·74 | ,, |
| Chromium B | 0·16 | .. | .. | 0·29 | .. | 17·00 | 25·00 | 45·55 | 65·90 | ,, |
| Nickel . . A | 0·19 | .. | .. | .. | 0·27 | 20·00 | 28·00 | 37·05 | 52·14 | ,, |
| Tungsten . C | 0·15 | .. | .. | W T | 0·40 | 18·00 | 25·50 | 39·60 | 60·10 | ,, |
| Copper 1240/0 | 0·19 | .. | .. | Cu | 0·40 | 24·00 | 43·00 | 21·45 | 28·22 | ,, |
| Silicon . B | 0·18 | 0·73 | .. | .. | .. | 19·00 | 29·50 | 34·02 | 52·66 | Double. |
| Aluminium C | 0·18 | .. | 0·66 | .. | .. | 18·00 | 27·00 | 33·00 | 52·14 | ,, |
| Chromium E | 0·12 | .. | .. | 0·84 | .. | 19·00 | 28·00 | 42·50 | 61·20 | ,, |
| Nickel . . C | 0·13 | .. | .. | . | 0·95 | 20·50 | 27·00 | 41·75 | 63·36 | ,, |
| Tungsten E/2 | 0·21 | .. | .. | W T | 0·81 | 18·00 | 26·25 | 37·60 | 53·26 | ,, |
| Copper 1240/1 | 0·25 | .. | .. | Cu | 1·39 | 32·00 | 43·00 | 31·41 | 50·92 | ,, |
| Silicon . C | 0·19 | 1·60 | .. | .. | .. | 25·00 | 33·00 | 35·10 | 54·52 | Double. |
| Aluminium F | 0·21 | .. | 1·60 | .. | .. | 13·00 | 26·00 | 36·35 | 67·00 | ,, |
| Chromium G | 0·21 | .. | .. | 1·51 | .. | 19·00 | 33·50 | 38·07 | 55·88 | ,, |
| Nickel . D | 0·14 | .. | .. | .. | 1·92 | 22·00 | 31·00 | 36·26 | 53·70 | ,, |
| Tungsten . G | 0·21 | .. | .. | W T | 1·49 | 19·50 | 28·50 | 36·90 | 54·88 | ,, |
| Silicon . D | 0·20 | 2·18 | .. | .. | .. | 25·50 | 34·00 | 36·50 | 59·96 | Double. |
| Aluminium H | 0·24 | .. | 2·24 | .. | .. | 18·50 | 28·50 | 33·00 | 48·62 | ,, |
| Chromium H | 0·39 | .. | .. | 2 54 | .. | 24·50 | 44·00 | 24·50 | 33·84 | ,, |
| Nickel . . E | 0·19 | .. | .. | .. | 3·82 | 25·00 | 33·00 | 35·85 | 55·86 | |
| Tungsten . H | 0·28 | .. | .. | W T | 3·40 | 23·00 | 34·00 | 33·90 | 53·02 | , |
| Copper . A/2 | 0·23 | .. | .. | Cu | 2·72 | 23·00 | 33·50 | 29·95 | 45·14 | ,, |
| Silicon . H | 0·26 | 5·53 | .. | .. | .. | 25·00 | 25·00 | 0·37 | 2·00 | Would not bend. |
| Aluminium I | 0·22 | .. | 5·60 | .. | .. | 27·00 | 36·00 | 6·45 | 6·16 | 16°, broken. |
| Chromium . J | 0·77 | .. | .. | 5·19 | .. | 20·00 | 55·00 | 8·20 | 6·88 | Double.[1] |
| Nickel . . F | 0·18 | .. | .. | .. | 5·81 | 28·50 | 37·00 | 33·15 | 51·62 | ,, |
| Tungsten . I | 0·38 | .. | .. | W T | 7·47 | 24·00 | 40·00 | 25·65 | 38·46 | ,, |
| Copper . . B | 0·16 | .. | .. | Cu | 4·40 | would not forge. | | | | ,, |

[1] Carbon in chrome sample too high to make direct comparison.

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TABLE IV.—FULL REPORT OF COMPRESSION TESTS OF FORGED UNANNEALED DIAMETER (0·50

These results are plotted

| Load in Tons per Square Inch. | A 0·27 per cent. Ni. | | B 0·51 per cent. Ni. | | C 0·95 per cent. Ni. | | D 1·92 per cent. Ni. | | E 3·82 per cent. Ni. | | F 5·81 per cent. Ni. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length | Increase of Diameter. |
| | Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. |
| 0 | .. | 0·7982 | .. | 0·7981 | .. | 0·7987 | .. | 0·7981 | .. | 0·7981 | .. | 0·7982 |
| 10 | nil | 0·7982 | nil | 0·7981 | nil | 0·7987 | nil | 0·7981 | nil | 0·7981 | nil | 0·7982 |
| 20 | nil | 0·8000 | nil | 0·7981 | nil | 0·7993 | nil | 0·7981 | nil | 0·7981 | nil | 0·7990 |
| 30 | 5 | 0·8110 | 5 | 0·8208 | 3 | 0·8176 | 3 | 0·8107 | 1 | 0·8053 | nil | 0·8004 |
| 40 | 8 | 0·8430 | 11 | 0·8511 | 8 | 0·8429 | 7 | 0·8327 | 5 | 0·8232 | 3 | 0·8160 |
| 50 | 17 | 0·8905 | 20 | 0·8993 | 15 | 0·8849 | 12 | 0·8665 | 10 | 0·8521 | 8 | 0·8390 |
| 60 | 26 | 0·9482 | 28 | 0·9550 | 23 | 0·9348 | 20 | 0·9125 | 17 | 0·8889 | 14 | 0·8700 |
| 70 | 33 | 1·0054 | 35 | 1·0065 | 31 | 0·9895 | 28 | 0·9666 | 25 | 0·9360 | 20 | 0·9106 |
| 80 | 40 | 1·0607 | 42 | 1·0645 | 38 | 1·0430 | 34 | 1·0170 | 31 | 0·9858 | 27 | 0·9516 |
| 90 | 45 | 1·1130 | 47 | 1·1153 | 44 | 1·1005 | 41 | 1·0756 | 37 | 1·0310 | 33 | 1·0364 |
| 100 | 50 | 1·1614 | 50 | 1·1623 | 49 | 1·1558 | 48 | 1·1296 | 42 | 1·0767 | 38 | 1·0416 |
| .. | (1) | | (2) | | (3) | | (4) | | (4) | | | .. |

[1] Specks began to show at 70 tons.
[2] No marked set-point, probably at about 26 tons. Small specks showed at
[3] Set at 28½ tons. Specks showed at 70 tons.
[4] Set at 27 tons. Small specks showed at 90 tons. Professor Arnold, for his Journal, No. 1, 1894), produced a similar material to this specimen D, viz., lowing results were obtained by him:—

| Load per Square Inch. | Reduction in Length per cent. | |
|---|---|---|
| | Normal. | Hardened. |
| Tons. 20 | 3 | .. |
| 40 | 17 | 3 |

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NICKEL-IRON ALLOYS; EACH SPECIMEN WAS 1 INCH IN LENGTH BY 0·7979 INCH SQUARE INCH AREA).

on Figs. 5 and 6, Plate 1.

| G 7·66 per cent. Ni. | | H 9·51 per cent. Ni. | | I 11·39 per cent. Ni. | | J 15·48 per cent. Ni. | | K 19·64 per cent. Ni. | | L 24·51 per cent. Ni. | | M 29·07 per cent. Ni. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. | Reduction in Length. | Increase of Diameter. |
| Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. | Per cent. | Inch. |
| .. | 0·7995 | .. | 0·7983 | .. | 0·7985 | .. | 0·7979 | .. | 0·7986 | .. | 0·7990 | .. | 0·7982 |
| | | | | | | | | | | | | nil | 0·7982 |
| nil | 0·7995 | nil | 0·7983 | | | | | | | | | 1 | 0·8020 |
| | | | | | | | | nil | 0·7986 | nil | 0·7990 | 4 | 0·8215 |
| nil | 0·8015 | nil | 0·7990 | | | | | | | | | 9 | 0·8475 |
| 4 | 0·8168 | nil | 0·7995 | nil | 0·7985 | nil | 0·7979 | | | 1 | 0·8050 | 15 | 0·8760 |
| 9 | 0·8420 | .. | 0·8000 | | | | | nil | 0·7990 | 5 | 0·8272 | 20 | 0·9125 |
| 16 | 0·8832 | 1 | 0·8013 | | | | | .. | 0·7997 | 8 | 0·8410 | 27 | 0·9520 |
| 22 | 0·9215 | 1 | 0·8023 | | | | | 1 | 0·8020 | 11 | 0·8557 | 32 | 0·9935 |
| 29 | 0·9650 | 1 | 0·8030 | nil | 0·8010 | nil | 0·7997 | 2 | 0·8095 | 14 | 0·8700 | 37 | 1·0360 |
| 35 | 1·0105 | 3 | 0·8144 | 1 | 0·8035 | 2 | 0·8068 | 4 | 0·8183 | 16 | 0·8830 | 42 | 1·0760 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | (b) | | .. | .. |

[a] Set at 22 tons; specks showed after 50 tons.
90 tons.
[b] Cracks showed after 60 tons.

Paper on "The Physical Influence of Elements on Iron" (Iron and Steel Institute C, 0·11 per cent.; Ni, 1·51 per cent.; and manganese practically absent. The fol-

| Load per Square Inch. | Reduction in Length per cent. | |
|---|---|---|
| | Normal. | Hardened. |
| Tons. | | |
| 80 | 49 | 33 |
| 100 | 57 | 44 |

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TABLE V.—CONDENSED TABLE OF COMPRESSION TESTS OF FORGED UNANNEALED NICKEL-IRON ALLOYS.

Each specimen was 0·7979 inch diameter, or 0·50 inch area and 1 inch long.

These results are plotted on Figs. 5 and 6, Plate 1.

Details of the effects at different loads varying from 10 to 100 tons per square inch are given in Table IV.

| Specimen Mark. | Analysis per cent. | | Tons per Square Inch. | |
|---|---|---|---|---|
| | C. | Ni. | Elastic Limit. | Shortening per cent. produced by a Load of 100 Tons. |
| | | | Tons. | Per cent. |
| A | 0·19 | 0·27 | 22 | 49·90 |
| B | 0·14 | 0·51 | 22 | 49·72 |
| C | 0·13 | 0·95 | 20 | 48·81 |
| D | 0·14 | 1·92 | 27 | 46·79 |
| E | 0·19 | 3·82 | 28½ | 41·38 |
| F | 0·18 | 5·81 | 40 | 37·76 |
| G | 0·17 | 7·65 | 40 | 33·66 |
| H | 0·16 | 9·51 | 70 | 3·23 |
| I | 0·18 | 11·39 | 100[1] | 1·05 |
| J | 0·23 | 15·48 | 80 | 1·62 |
| K | 0·19 | 19·64 | 80 | 3·65 |
| L | 0·16 | 24·51 | 50 | 16·11 |
| M | 0·14 | 29·07 | 20 | 41·58 |

[1] Necessarily estimated.

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TABLE VI.—COMPARISON OF COMPRESSION TESTS ON FORGED UNANNEALED SILICON, ALUMINIUM, CHROMIUM AND NICKEL-IRON ALLOYS.

These results are plotted on Fig. 7, Plate 1.

| Steel. | Specimen Mark. | Analysis. | | | | | Tons per Square Inch. | |
|---|---|---|---|---|---|---|---|---|
| | | C. | Si. | Al. | Cr. | Ni. | Yield or Set Point. | Shortening produced by a Load of 100 Tons. |
| | | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Tons. | Per cent. |
| Silicon . . . | .. | .. | .. | .. | .. | .. | .. | .. |
| Aluminium . . | A | 0·22 | .. | 0·15 | .. | .. | .. | 51 |
| Chromium . . | A | 0·07 | .. | .. | 0·22 | .. | .. | 58½ |
| Nickel . . . | A | 0·19 | .. | .. | .. | 0·27 | 22 | 50 |
| Silicon . . . | B | 0·18 | 0·79 | .. | .. | .. | .. | 50 |
| Aluminium . . | C | 0·18 | .. | 0·66 | .. | .. | .. | 49 |
| Chromium . . | C | 0·15 | .. | .. | 0·48 | .. | .. | 50½ |
| Nickel . . . | B | 0·14 | .. | .. | .. | 0·51 | 22 | 50 |
| Silicon . . . | .. | .. | .. | .. | .. | .. | .. | .. |
| Aluminium . . | E | 0·26 | .. | 1·16 | .. | .. | .. | 47 |
| Chromium . . | E | 0·12 | .. | .. | 0·84 | .. | .. | 48 |
| Nickel . . . | C | 0·13 | .. | .. | .. | 0·95 | 20 | 49 |
| Silicon . . . | .. | .. | .. | .. | .. | .. | .. | .. |
| Aluminium . . | F | 0·21 | .. | 1·60 | .. | .. | .. | 48 |
| Chromium . . | G | 0·21 | .. | .. | 1·51 | .. | .. | 44½ |
| Nickel . . . | D | 0·14 | .. | .. | .. | 1·92 | 27 | 47 |
| Silicon . . . | E | 0·20 | 2·67 | .. | .. | .. | .. | 38 |
| Aluminium . . | H | 0·24 | .. | 2·24 | .. | .. | .. | 45½ |
| Chromium . . | H | 0·39 | .. | .. | 2·54 | .. | .. | 29½ |
| Nickel . . . | E | 0·19 | .. | .. | .. | 3·82 | 28½ | 41 |
| Silicon . . . | G | 0·25 | 4·49 | .. | .. | .. | .. | 32 |
| Aluminium . . | I | 0·22 | .. | 5·60 | .. | .. | .. | 36½ |
| Chromium . . | J | 0·77 | .. | .. | 5·19 | .. | .. | 11 |
| Nickel . . . | F | 0·18 | .. | .. | .. | 5·81 | 40 | 38 |
| Silicon . . . | .. | .. | .. | .. | .. | .. | .. | .. |
| Aluminium . . | .. | .. | .. | .. | .. | .. | .. | .. |
| Chromium . . | K | 0·86 | .. | .. | 6·89 | .. | .. | 14½ |
| Nickel . . . | G | 0·17 | .. | .. | .. | 7·65 | 40 | 34 |
| Silicon . . . | .. | .. | .. | .. | .. | .. | .. | .. |
| Aluminium . . | .. | .. | .. | .. | .. | .. | .. | .. |
| Chromium . . | M | 1·27 | .. | .. | 11·13 | .. | .. | 19 |
| Nickel . . . | I | 0·18 | .. | .. | .. | 11·89 | 100[1] | 1 |

[1] Necessarily estimated.

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TABLE VII.—ELECTRICAL CONDUCTIVITY TESTS OF NICKEL-IRON ALLOYS MADE FOR THE AUTHOR BY PROFESSOR BARRETT, F.R.S., ROYAL COLLEGE OF SCIENCE, DUBLIN.

These results are plotted on Fig. 9, Plate 1.

| Specimen Mark. | Analysis. | | Condition of Material. | Electrical Conductivity with : | |
|---|---|---|---|---|---|
| | C. | Ni. | | Cu = 100. | Fe = 100. |
| | Per cent. | Per cent. | | | |
| D | 0·14 | 1·92 | Unannealed | 8·00 | 51·5 |
| E | 0·19 | 3·82 | ,, | 6·88 | 44·3 |
| I | 0·18 | 11·39 | ,, | 4·49 | 28·9 |
| K | 0·19 | 19·64 | ,, | 4·00 | 25·7 |
| L | 0·16 | 24·51 | ,, | 2·67 | 17·2 |
| L | 0·16 | 24·51 | Annealed | 3·70 | 23·84 |
| L | 0·16 | 24·51 | Water quenched | 3·02 | 19·45 |
| S | .. | 31·00 | Unannealed | .. | 12·02 |

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## APPENDIX IV.

Dr. J. A. Cramer published in 1741 a valuable work of reference on "The Elements of the Art of Assaying Metals" (dedicated to the Honourable J. Winthrop, Esq., Fellow of the Royal Society, and printed for Thomas Woodward at the Half Moon, between the Temple Gates). In a quaint preface he states that the experiments described in his book represent "Indefatigable Labour, the closest inspection, the work of Hands that were not afraid of the Blackness of Charcoal." He describes very fully the properties of nickel and cobalt ores as then known, and of the former says: "Nevertheless there is a certain Mineral that deserves to be referred to in this Class: (that is, the class of arsenic and arsenical minerals) it is rich in Arsenick, somewhat like cobalt, of a gray reddish Colour. It looks like a Semi-metal; it contains also a little Copper and a little Sulphur, the Germans call it 'Kupfer-Nickel.'" In describing copper ores he says: "The Ore which has been mentioned under the title of Kupfer-Nickel when we treated of Arsenic and arsenickal Minerals, may have a Place here, but only as being improper. It contains a Quantity of Copper not inconsiderable, but it is neglected because the cobalt wherewith it is encumbered renders it almost intractable. In the mean Time you are to observe that what renders Ores intractable is not the Arsenick itself, but a kind of Earth, which is always united to the proper Minerals of Arsenick, especially to Cobalt, which resists Fusion very much, and by Means of the Arsenick that is fixt in it, adheres with great Tenacity to Metals, especially to Copper and Iron."

One other quaint reference may be made, and its advice as regards keeping ourselves in touch with foreign technical progress is as good to-day as when first given. It should be the aim of our and other Institutes to try and meet the same want which was then felt as to fuller information being made available, and especially regarding foreign technical literature, a matter which we often overlook. When speaking of Emanuel Swedenborgius' great work, "Principia Rerum Naturalium" (Dresden 1734), and of that portion dealing with "Methods and newest improvements in metallic work in all places beyond the sea, but particularly of those in England and our Colonies in America," Dr. Cramer says: "It is to be wished we had extracts of this work in English. So industrious are the Swedes in improving themselves in the Art of Metallurgy that they send young Gentlemen early to travel not only all over England, but all over Europe, to learn everything new in regard to Mines; while we in England sit still at home and seldom go beyond a County or two; I think if more diligent search were to be made by Persons of Skill there is great reason to believe that Nature hath enriched these our Isles with as great Subterranean Treasures, even the virgin silver of Potosi not excepted, as any other Spot of the same extent." How prophetic in face of our last year's output of over 200,000,000 tons of coal and over 8,000,000 tons of pig-iron, produced largely from English ores. Dr. Cramer's foresight of nearly a century and a half ago is remarkable, but whether "our young Gentlemen are sent early and often enough to travel and learn everything new" is perhaps still worth consideration. His comments too on some of the metallurgists of the day are curious as well as instructive. For instance, he speaks of one of them as follows: "He seems to write like one who had never blacked his Fingers or singed his Beard in Metallick Operations."

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## Discussion.

Mr. Hawkshaw. Mr. J. C. HAWKSHAW, Member of Council (Chairman), felt sure the members would pass a vote of thanks to the Author for his Paper. The abstract which had been read really gave a very small idea of the amount of matter contained in it. The labour involved in the investigations carried out by the Author would be seen from a statement in the Paper, where the Author said that the theoretical opinion could only be accurately determined by the preparation of ten specimens of each of the Author's nickel percentages, the carbon varying by tenths, which would give 140 different specimens, each requiring 500 to 600 different tests. The metal seemed to have been known at a very early date to the Chinese, who appeared to have used nickel alloys, but he did not see any mention of the Japanese having done so. The Japanese were most skilful workers in metal, and he supposed their steel sword-blades, made five or six centuries ago, had never been surpassed. They were also very clever in working alloys, and if Sir William Roberts-Austen had been present he might have told something of the use the Japanese had made of nickel. Mr. Hawkshaw remembered seeing an analysis of Japanese alloys made by him which contained nickel.

Mr. Hadfield. Mr. R. A. HADFIELD exhibited on the screen a series of photographs of tests on rivets made with carbon steel and nickel steel, kindly furnished him by the Bethlehem Iron Company of Pennsylvania. The nickel steel showed a great superiority over the former alloy, the shearing stress being about twice as great, viz., from 36 tons to 42 tons per square inch as against carbon steel 19 tons to 25 tons, so that a $\frac{3}{4}$-inch rivet or a $\frac{7}{8}$-inch rivet would give as good effect as a $1\frac{1}{4}$-inch rivet in the ordinary carbon steel used for this purpose. The first photograph represented two very large nickel-steel ingots, each about 100 tons in weight, and containing about 3 tons of metallic nickel. The next photograph illustrated the nickel steel crank-shaft produced by Mr. F. Krupp, of Essen, used in the large steamer "Kaiser Frederick der Grosse." It was 23 inches in diameter, of a total length, when built up, of 196 feet, and the total weight amounted to about 86 tons. He thought, however, that the best indication of the startling advances made during the past few years was found in armour plates. He selected these as illustrating the advance from wrought iron to carbon steel and eventually to

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nickel steel. The next photograph therefore showed the effect on a 15½-inch wrought-iron plate of a 9·2-inch cast-steel projectile which had been fired against it. The striking velocity was about 1,900 foot-seconds and striking energy 10,000 foot-tons. It was a solid shot and pierced the plate, several feet of wood backing, and made an impression on a wrought-iron plate in the rear to a depth of about 7 inches or 8 inches, the theoretical perforation of wrought iron being about 18 inches. From wrought iron the advance was made to compound steel plates. The face of the plate was hard steel, naturally hard, not quenched in any way as now, and the next photographs showed the result of a 13·5-inch projectile fired against an 18-inch compound plate. The striking velocity was 1,986 foot-seconds, and the striking energy 33,400 foot-tons. One photograph represented the face of the plate after the impact, and another the rear of that plate. The projectiles pierced the plate, about 10 feet or 12 feet of oak backing, and then met an old wrought-iron plate about 10½ inches in thickness, in which there was a number of previous shot-holes, made its way through that plate and finally was found broken; he thought it had done a very fair amount of work. The next photograph represented a 10½-inch compound plate attacked by 6-inch projectiles. The velocity was about 1,840 foot-seconds. The remarkably hard nature of the face portion of the plate could be seen; it contained about 1¼ per cent. of carbon. This trial was doubly interesting because on the table he had been able to place, through the kindness of Messrs. Schneider of Le Creusot, France, photographs representing the trials in June, 1890, of the first large nickel-steel armour-plate made either in Europe or America. Though not quite so thick (9¾ inches) as the compound plate just referred to (10½ inches) it formed an excellent comparison between the two materials. Apparently the difference in resistance was not very great, but bearing in mind the thinner section of the nickel-steel plate it was probably the better of the two. In each case the same calibre of projectile was used, viz., 6 inches. He was referring to plates which were not in any way hardened on their surfaces. The next photograph illustrated the advance to ordinary or mild steel and was a comparatively recent trial. The War Office had kindly given him permission to use these photographs. The first slide represented a mild-steel plate 15½ inches in thickness, not nickel steel, and not face-hardened in any way. It was attacked by a 10-inch projectile, fired at a velocity of 1,930 feet per second. The projectile pierced the plate and was found about 20 feet on the other side, having bored its way into the earthwork.

Mr. Hadfield.

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Mr. Hadfield. It was uninjured. The steel represented by the punched-out hole would weigh no less than 360 lbs., and nearly the whole of this was absorbed by the plate. He would now refer to face-hardened plates, and the first photograph was that of a Bethlehem plate 15½ inches in thickness, attacked by two 10-inch projectiles. The face-hardening had been rather too much for the shot. This plate was of the old Harvey type. In the next photograph was seen the latest development, a special nickel-steel plate manufactured by the Bethlehem Company, only 6 inches in thickness and face-hardened, practically known as the Krupp type. This plate had resisted the attack of no less than six rounds of 8-inch projectiles, with velocities ranging from 1,520 to 1,828 foot-seconds; in fact, it had absorbed 30,000 foot-tons of energy. This 6-inch plate was found to be equal to a 15-inch wrought-iron plate. Although he was not able to show a rear view, apparently from the front view of the plate there were no cracks. As all the British trials were with shot made by his firm, extending over a number of years, it showed that there was no reason to go abroad for this weapon of defence, the Hadfield shot were, and always had been, produced independently of foreign aid. He proceeded to describe the specimens exhibited on the table. He had a specimen of steel containing about 5 per cent. of manganese and about $\frac{4}{10}$ per cent. of carbon; its extraordinary brittleness was hardly to be realized except by testing the material. It was steel—if it could be called steel—almost like sandstone. It was quite possible to take a sample and crush it in a mortar, it was therefore even weaker than cast iron. Another of the alloys exhibited contained 12 per cent. of nickel and was quite wanting in toughness. The extraordinary result was, however, obtained, that if the two brittle percentages of each element were combined, a material was produced which could be bent double cold, as illustrated by the specimens on the table. He thought it was very difficult for metallurgists to give any satisfactory explanation of these results. There was also shown a compression specimen containing 12 per cent. of nickel, that in its "natural" and forged conditions, with no less than 100 tons compression stress per square inch, had not shortened more than 1½ per cent., whilst alongside, to illustrate the difference, was a test-bar of ordinary mild steel, which under the same stress shortened no less than 55 per cent. The interesting point regarding the nickel-steel specimen was that the peculiar hardness noticed was that of its natural, not quenched, condition.

Prof. Arnold. Professor J. O. ARNOLD regarded the discovery of a distinct critical point in the mechanical properties of iron and nickel at

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about 12 per cent. to 15 per cent. nickel as specially interesting. Prof. Arnold.
He had made experiments with nickel steel, testing 8 per cent. and 30 per cent. and upwards, and found no very great variation, and he was somewhat astonished when the Author informed him that a compound existed between 12 per cent. and 15 per cent. of nickel. On testing the matter he found that the Author's observations were absolutely accurate; and that he had discovered a critical point which had evaded the vigilance of other observers. As the Author had pointed out, there was great difficulty in preparing iron and nickel alloys, very low in the elements of carbon and manganese, so as to ascertain exactly the effect of the nickel on the iron. The Author's results had been obtained, he believed, with the ordinary cube nickel, with certainly very good analyses of carbon, averaging about 0·2 of carbon, and manganese 0·7. But he ventured to think, and he thought the Author himself had rather predicted the fact, that if carbon and manganese could be got down still lower, the properties specified would be found to undergo considerable modification. In the steel works attached to University College, Sheffield, he had been able to make the purest series of iron nickel alloys which had ever been prepared, and which had fully verified the Author's prediction as to the extraordinary properties to be expected. It was found impossible to obtain good results by using the ordinary cube nickel, because it almost invariably contained oxygen, which led to red-shortness in the alloy, necessitating the use of a large quantity of manganese. At Sheffield he had a curious experience which might not be uninteresting to the members. In preparing nickel alloy, which was made in the open-hearth furnace and cast into 8-inch ingots, with 17 per cent. of nickel and 30 per cent. of iron—it had never been done in such large ingots before—when the ingots were cast the extraordinary spectacle was observed of an 8-inch mould travelling right up the ingot for the space of at least 1 foot. The mould was rising clean up the ingot. It was thought then that the ingots must be very full of gas. One of the ingots was sent to a director in a Sheffield works, who had expressed a desire to see how the ingot would forge. He stated that the ingot was put into an ordinary heating furnace, and in about 20 minutes the forge manager reported to him that the ingot had exploded like a bombshell and blown the furnace up. The ingot was found to be exactly like a honeycomb and quite full of gas. The ingots were broken up and the pieces were re-melted with 1 per cent. of manganese to ensure the removal of all oxygen, and with



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Prof. Arnold. that specially-prepared alloy, first prepared in the open-hearth furnace and then re-melted in the crucible, they had been able at the University College Steel Works to produce remarkable alloys of iron nickel. Again, it was remarkable that with about 12 per cent. to 15 per cent., as the Author pointed out, there was an extraordinary maximum stress of 90 tons per square inch, but without ductility. By removing the carbon and manganese, the carbon to about 0·1 per cent. and the manganese to about 0·15, the remarkably high tensile stress was still retained, but there was a very considerable amount of ductility. The stress of the speaker's alloy was 88 tons with an elastic limit of 59 tons per square inch. The elongation, instead of being practically nothing, was 11 per cent. in 2 inches, and the bending angle over $\frac{5}{8}$ radius was 167°. That was an alloy with practically 90 tons of stress, and which would bend nearly double, and an alloy that would do that was certainly a very remarkable testimony to the power of nickel on iron. His experience had been exactly similar to that of the Author with reference to the exceedingly small effect of annealing or hardening upon nickel alloys, particularly the alloy at about 13 per cent. of nickel. The Table on the next page showed clearly the small amount of mechanical effect produced by annealing, or by hardening the nickel steels, on the critical point. There was another remarkable property of nickel to which he should like to call attention which he found out some time ago, and that was that if a high nickel steel was taken containing high carbon, and was drastically annealed or rolled at a pretty low temperature, the whole of the carbon separated as graphite. He had a graphitic test-piece which was quite black in the fracture. That piece contained in round numbers 34 per cent. of nickel, with 1·3 per cent. of carbon, about a turning-tool temper. After the rolling nearly all the carbon had separated as graphite, and only 0·05 of the carbon remained in the combined condition. And exactly the same result was obtained on annealing high nickel steels—the whole of the combined carbon was thrown out and occurred in the mass in the free state. With reference to corrosion, there again his experience had been very similar to that of the Author. He had been able to make experiments, not only on the laboratory scale, but on a practical scale. There was no doubt that 33 per cent. of nickel alloy would resist corrosion to a far greater extent than ordinary steel; but its power of resisting corrosion had been exaggerated, and usually it seemed to go very suddenly. He knew of a case in which nickel steel was placed in a vessel which underwent very severe conditions as to corrosion, and the engineers

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| No. | Section. | Analysis. | | | | | | | | Tensiles. | | | | Bending. | Specific Gravity. | Hardness. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ni. | C. | Gr. | Si. | Mn. | S. | P. | Al. | Elastic Limit. | Maximum Stress. | Elongation on 2 inches. | Reduction per Cent. | ½ inch Radius. | | |
| | | | | | | | | | | | Tons per Sq. In. | | | | | |
| 546 | {2 ins. by $\frac{3}{16}$ in.} | 6·42 | 0·11 | .. | 0·03 | 0·07 | 0·03 | 0·02 | 0·02 | 30·46 | 39·76 | 30·0 | 43·6 | .. | .. | .. |
| 549 | {$\frac{5}{8}$ in. radius} | 7·24 | 0·12 | .. | 0·06 | 0·12 | 0·03 | 0·02 | 0·02 | 32·50 | 38·20 | 27·5 | 69·2 | 180° U | 7·855 | 4·0 |
| 548 | {$\frac{5}{8}$ in. radius} | 12·78 | 0·10 | .. | 0·05 | 0·19 | 0·05 | 0·02 | 0·02 | N 58·75 | 88·10 | 11·0 | 45·8 | 167° | 7·855 | 5·0 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | A 54·50 | 79·50 | 10·5 | 38·5 | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | H 62 20 | 91·30 | 10·0 | 44·5 | .. | .. | .. |
| 545 | {2 ins. by $\frac{3}{16}$ in.} | 12·88 | 0·14 | .. | 0·04 | 0·10 | 0·03 | 0·02 | 0·02 | 60·39 | 80·56 | 13·5 | 30·8 | .. | .. | .. |
| 512 | {2 ins. by $\frac{3}{16}$ in.} | 33·45 | 0·10 | .. | 0·09 | 0·35 | 0·03 | 0·02 | 0 02 | 28·86 | 38·92 | 33·0 | 46·1 | 180° U | 8·065 | 4·5 |
| 511 | {2 ins. by $\frac{3}{16}$ in.} | 33·66 | 0·05 | 1·25 | 0·03 | 0·21 | 0·035 | 0·02 | 0·02 | 25·88 | 28·23 | 3·0 | 7·3 | .. | 7·795 | .. |
| | | | Total carbon 1·30 per cent. | | | | | | | | | | | | | |





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Prof. Arnold. were very delighted at the end of 2 months to find no corrosion appeared to have taken place. Within a fortnight afterwards the whole mass seemed to have corroded, and the corrosion came on very suddenly. There was no doubt that if there was any considerable quantity of iron present in the nickel there was certainly sooner or later more or less corrosion. There was one little point in which the speaker's results had been rather different from those of the Author, and that was on the question of the specific gravity. He found it rise with the percentage of nickel, whereas the Author's results were somewhat erratic in that respect. With reference to the physical points in the magnetic test carried out by Professor Barrett, and as far as he could see in the recalescence test by Mr. Osmond, there was no critical point in the physical tests corresponding to the alloy. He sincerely hoped it would not be said again that that remarkable alloy was due to some allotropic modification of iron. He thought there was very little doubt that the extraordinary combination was of a very similar nature to that familiar to most engineers; if 90 per cent. of copper was taken and 10 per cent. of aluminium added to it, when an alloy was obtained which had undergone as great a change from its constituents as the iron and nickel, and he thought the phenomena of the 12 per cent. or 15 per cent. alloy was very much of the same order as that of the aluminium bronze.

Mr. Snelus. Mr. G. J. SNELUS had always considered there were special reasons why most important results might be looked for from the alloy of iron and nickel. It was most singular that nickel and iron were the most prominent metals found in meteorites. A great number of other metals were found in small traces, but in considerable quantities very few other metals were found in the metallic meteorites, and it did appear as though Nature was teaching the lesson that nickel and steel was a combination which would be beneficial. But it was also known that iron, nickel, chromium, and manganese were very closely allied in all their chemical properties, but iron and nickel seemed to be more closely allied than either chromium or manganese. Nickel had a solubility for carbon very much greater than that for iron or manganese, and there were other very important things which might follow from that. For instance, Mr. Osmond had been working at the production of diamonds by obtaining a large proportion of carbon in cast iron and then separating the diamondiferous matter from the product. In all probability, with such a highly powerful solvent for carbon as nickel, it might be well if further experiments were

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made in the same direction as Mr. Osmond's with regard to nickel and carbon in the separation of the diamondiferous form of carbon from its nickel absorbent. There was also the remarkable property of nickel of occluding oxygen. It was known that iron was a very powerful occluder of oxygen, and very many years ago he had called attention to the occlusion of oxygen in iron and the very powerful effect it had. He also at that time made a rough estimate of the quantity of oxygen that was absorbed in Bessemer steel, and those figures, although roughly made at the time by the use of manganese, had been confirmed later. The effect of oxygen in metals required a great deal more study, and the remarkable explosion of the nickel ingot called special attention to that point. There was no doubt that many metals had an enormous capacity for taking up the gases while they were fluid and giving them out again while they were solidifying. He had always thought that one of the most important investigations that could be made in connection with steel was to find out how to prevent the metals occluding oxygen. He believed that if that could only be done in a scientific manner enormous advantages would be gained in the production of steel. If nickel had that power in a so much greater degree than iron it might be well to study the combination rather than to attempt to work out the subject with iron. There was no doubt that the alloys of nickel and iron were to be of very great value in the future. The wonderful results that had been already produced by the alloy of nickel which was used for armour-plates and projectiles he thought were only a beginning, and a great deal more had yet to be done, and a great deal of importance would arise from further investigation of those nickel alloys. It seemed to him a question whether it was not possible to get a better result by the use of three bodies—the use of iron, nickel, and chromium, for instance—or even four. It appeared as though one element seemed to counteract the bad effect of another. In slags, for instance, a better result was obtained from using three bases, and so in the alloys it might be possible to get better results where either three or four of the closely-allied metals were used in order to form the alloy. It was evident there was so much to be done in that direction that the necessity was emphasized of a union between the Institution of Civil Engineers, the Mechanical Engineers, and the Iron and Steel Institute in order to have a laboratory or arrangements for experiments and other investigations which could be carried out on a large scale, and which would undoubtedly produce very valuable results for the public generally.

Mr. Snelus.

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Prof. Unwin. Professor W. C. UNWIN did not find it mentioned in the Paper that an attempt was made by Sir William Fairbairn, in the year 1858, to ascertain how cast iron would be improved by the addition of nickel.[1] At that time not much advantage was gained from adding nickel to the iron. As to the measure of the hardness of the alloys, the Author appeared to rely upon a compressive test. He took as the measure the compression of a test specimen under 100 tons per square inch, and in Fig. 5, Plate 1, there was a plotting showing very remarkably the exceptional character of those alloys which had been already referred to in the discussion. In taking the compression under a load of that kind, as a measure of hardness, it was necessary to select some quite arbitrary test pressure—in that case 100 tons per square inch—from which the results were plotted. He thought if the Author would plot the results for 50 tons per square inch and 150 tons per square inch he would obtain curves of a different character. The selection of 100 tons per square inch had probably exaggerated the depression of the curves for those two or three particular alloys. A compression test of hardness involved the use of an arbitrary test pressure. The mechanical properties of the alloys of nickel with iron were most important, and the characteristic of those alloys which had led to their actual use was that they provided a material with an exceedingly high elastic limit without great loss of ductility or toughness. The Author had given, from a Paper by Mr. Porter of the Bethlehem Works, some very interesting results of tests; but the figures were so very much alike that perhaps one point might be missed, namely that the simple nickel steel in each case had as high a breaking stress, and as high an elastic limit, as the medium carbon steel which had been oil-tempered, and that when the nickel steel was oil-tempered also, the test was very much better than that of the medium hard carbon steel. The Author had referred to the use of nickel steel alloys in America for piston-rods and the like. In America nickel steel was used rather largely for structures which were subjected to very considerable variation of stress. It could easily be seen, according to the indications of Wöhler's law, that material with a high elastic limit, and, therefore, a large elastic range, ought to be able to carry a reciprocating stress better than a material with a low elastic limit. It might not be very much stronger, but its high elastic limit would give it a great advantage. It appeared that, in America, engineers were beginning to use steel of a harder

[1] Mem. Manchester Phil. Soc., 1858.

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quality for a number of purposes than was usually in England thought desirable. Mr. Porter had not given endurance tests of nickel steel; but he had given endurance tests of moderately high carbon steel subjected to alternations of stress, and had indicated that steel with a high elastic limit bore a reciprocating stress very much better than one with a lower elastic limit, and the results would apply equally or even more to nickel steel. Taking carbon steel with 0·25 per cent. of carbon and under a variation of stress amounting to 20 tons per square inch, that steel would only carry 200,000 changes of load before it broke. Such steel hardened but little by quenching, but after quenching it carried 300,000 changes of load before breaking. Taking carbon steel, again, with about 0·5 per cent. of carbon, that steel carried 800,000 changes of load before breaking in its normal state, and 1,600,000 changes of load when quenched. Going one step further, and taking steel with six-tenths of carbon, that steel with the same stress of 20 tons, carried 3,700,000 changes of load in its normal state and 4,300,000 changes of load when hardened. The effect of the higher range of elasticity on the endurance, or absence of fatigue of the material, was in that case very striking. Prof. Unwin.

Prof. J. O. Arnold remarked that at Sheffield the actual hardness of the alloys had been measured on the mineral scale, and it was certainly very much out of proportion to the crushing test. With 7 per cent. of nickel on the mineral scale the hardness was 4; with 13 per cent. of nickel, the critical point, the hardness rose a unit to 5; and at 33 per cent. of nickel the hardness fell back to 4·5. So that the variation of true hardness was comparatively small. Prof. Arnold.

Professor G. Forbes was specially interested in the portion of the Paper dealing with the magnetic properties of the iron-nickel alloys, which had such an important bearing on electrical work. The first point of special interest arose from the very remarkable experiments upon some specimens of nickel steel which were given by Messrs. Hadfield to Dr. John Hopkinson,[1] and which were reported upon by him. One particular specimen, if he remembered aright, had 25 per cent. of nickel, a proportion which was mentioned under its magnetic properties in the Paper, and in which he found that after raising it to a high temperature it lost almost entirely its magnetic properties, even upon cooling again, and regained its magnetic properties only on being reduced to a very Prof. Forbes.

[1] Proceedings of the Royal Society, Dec. 2, 1889; Jan. 23, 1890; May 1, 1890.

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Prof. Forbes. low temperature indeed. It then became magnetic, and either by raising it to the high temperature, or reducing it to the low temperature, it could be left permanently at the normal temperature in either condition. It was stated by the Author that the behaviour of a 25 per cent. nickel steel containing, say 0·2 per cent. of carbon, was very different from a 25 per cent. nickel steel containing 1 per cent. of carbon, and hence the necessity for great care in knowing the whole history of the specimen being examined. The Author continued:—"Take, for example, the statements which have been given by several experimenters, that nickel iron alloys can be made magnetic or non-magnetic at will." He did not know whether the Author wished the conclusion to be drawn from his remarks that there was a difficulty in obtaining the results which Dr. Hopkinson obtained. It would be of great interest to those engaged on magnetic work if the Author would explain the circumstances under which Dr. Hopkinson obtained those most remarkable results. On the next page the Author said:—"It has been stated that 25 per cent. nickel steel becomes non-magnetic at 520° C., and remains so after plunged at this heat into cold water; but the above experiment did not indicate this result, and the Author thinks the specimens must have also contained comparatively high percentages of carbon." He thought it was very desirable that that point should be cleared up, and that the members should understand exactly what was the behaviour of the nickel-iron alloys with regard to their losing their magnetism. The magnetic properties of iron were long known to be affected by nickel, and from experiments which had been made up to about the period of Dr. Hopkinson's Paper, it was generally found that nickel was deleterious to the magnetic permeability of the iron. Few people in the year 1893 or 1894 would have expected that the addition of nickel to iron would not be injurious to the magnetic permeability of the iron. At the time when the Niagara dynamos were being designed there were designs from numerous makers, some with rotating field-magnets and some with rotating armatures, but in each case the rotating part was always in the centre, whether it was a field magnet or an armature. It was necessary, to fulfil the conditions enforced by the turbine makers for the regulation of their turbine effectively, to have a certain fly-wheel effect. While the turbines were so constructed as to support by the water-pressure the whole weight of the revolving part of the turbine, the revolving vertical shaft, and the revolving part of the dynamo at the top, that weight was not to exceed a certain amount. It appeared from all the

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designs of dynamos sent in that if a fly-wheel was added to the revolving part of the dynamo the weight invariably was too great for the pressure of the water to support on any piston that could be made in the turbines. It seemed in fact that the turbines already constructed for the work would have to be given up, until it occurred to him that an entirely different design could be obtained by making the field-magnet revolve externally to the armature, leaving the armature fixed in the centre, so as to have a ring of steel revolving outside it, with the pole-pieces attached on the inside of the ring pointing inwards towards the armature. That gave a very strong mechanical structure for the attachment of the pole-pieces to the iron inside the ring, and it also gave a maximum fly-wheel effect, with no necessity for a great weight to be added to it in the form of a special fly-wheel. On calculating the weights required for producing the dynamo, at 5,000 HP. in that case, he found that it was thoroughly satisfactory, and it was that type of dynamo that overcame the difficulty originated by the necessities of the turbine maker. Before that was put into execution and carried out so splendidly by the magnificent work of the Westinghouse Company, the Bethlehem Ironwork Company were at work on nickel steel, and it was suggested to him that it would be desirable to introduce nickel steel for the ring which supported the pole-pieces on the inside. That ring was the critical part mechanically, so far as strength was concerned, of the huge dynamos, dynamos with a diameter of about 11½ feet, and revolving at 250 revolutions per minute. The ring was revolving at about 2 miles a minute, and the centrifugal force acting upon the ring itself was increased by the enormous mass of the pole-pieces with their windings which rested on the inside of the ring. Consequently, it became a matter of the utmost importance that the ring should have the greatest strength possible, and for that reason the Bethlehem Ironworks suggested it would be advisable to use the nickel steel they were manufacturing. At first he was inclined to reject it because of the deleterious effect that the introduction of the alloy was expected to have upon the magnetic permeability of the iron. Most fortunately, at the same period, experiments were being made in America on that very point with nickel steel, and the results showed the magnetic permeability to be entirely satisfactory for the percentage of nickel they were using. Consequently, the dynamos were made of that material, and nothing could have been better, combining the enormous tensile strength with the

Prof. Forbes.

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Prof. Forbes. satisfactory permeability of the material. For a structure of that sort, where such high magnetic power was required combined with great tensile strength, such a material was of the utmost value. At the same time he would suggest that so important was it that it almost seemed that too little attention was given in the Paper to the magnetic properties of the material. The tests which had been made were scarcely calculated to give quantitive results as to the permeability of the alloys. He thought it would be most desirable if the same materials, of which the whole properties of the tensile strength and elongation were known, were also submitted to tests as to their magnetic properties, both permeability and hysteresis.

Mr. Blount. Mr. B. BLOUNT remarked that great as was the fund of information provided by the Author's researches, it would be indefinitely increased by an investigation of nickel-iron alloys containing appreciable percentages of carbon. The Author had already indicated the enormous labour of such an inquiry, if it was to be exhaustive; but it was possible that certain of the more promising alloys containing carbon might be examined, without trying to be rigidly systematic. As to the difficulties of determining hardness, the selection of a particular load and the observation of the behaviour of the alloy under it was not unexceptionable as a means of judging the hardness of a given material, but he thought Professor Unwin had done much to remedy that inconvenience by devising a test in which the surface of the alloy was deformed by a wedge-shaped test-piece and the flow of the metal was obtained by the depression of the wedge. He had employed the method put forward first by Turner of drawing over a polished surface a diamond point loaded with a particular weight and ascertaining as nearly as possible the load at which the diamond point first scratched the surface. It had recently been found that the results by the two methods were entirely comparable, but he still thought there was much to be done before a standard method for determining hardness could be arrived at. When nickel steel was first brought into use much was expected of it in its resistance to corrosion of all kinds, and he suspected that its employment in ships of war was somewhat influenced by the belief, not only that its mechanical properties would adapt themselves to such uses, but also that its indifference to corrosive agencies would make it particularly applicable to sea-going vessels. That would apply more particularly to a lighter class of vessels—to torpedo-boat destroyers and so forth—the plates



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of which were necessarily very thin, and in the construction of propellers, where corrosion was a serious matter, in that their contours were impaired long before their actual destruction. He regretted to find that the high resistance to corrosion which had been anticipated was not justified by the Author's experiments. The special set of experiments used by the Author was the observation of the behaviour of his alloys in one particular corrosive agent, sulphuric acid of a particular strength, and observations of the appearance and condition of propellers and the like when exposed to sea-water. He thought in a matter of that kind systematic observations could hardly be made too copiously, and if that series of experiments were extended valuable information might be gained which possibly might resuscitate the reputation of nickel alloys as corrosion-resisting material. Mr. Blount.

Mr. W. W. MARRINER thought that more information with respect to the use of nickel steel for piston-rods, connecting-rods and shafting of quick-running machinery would be of interest. It was shown by the Author that there was a critical point at which a very slight variation in the composition entirely altered the physical qualities of the steel, and in another part of the Paper the Author gave Tables showing the compositions which he intended to get in his experimental test-pieces and the compositions which he had really obtained, and these Tables pointed to the difficulty of getting exactly the required mixture, and he thought it was fair to suppose that the compositions, when the alloys were made as commercial materials, would vary even more than they did in the experimental pieces, and a ductile metal of a certain composition might be aimed at, but which would turn out to be really too hard for certain purposes. He should be glad if the Author could give information which would restore confidence as to the possibility of getting exactly what was required. As to the corrosion, the Author made a very serious statement, namely, that the deterioration set in very rapidly, and that there came a time when a sudden breakdown occurred, and that whatever might be the corrosive medium employed. On another page the Author gave the result of some experiments, and there the resistance to corrosion was greater as the percentage of nickel increased; but were these results obtained after the breakdown point had been arrived at or before? In conclusion, he would like to add his tribute of praise to the Author for bringing forward such an exhaustive Paper on a subject that was attracting so much attention at the present time. Mr. Marriner.

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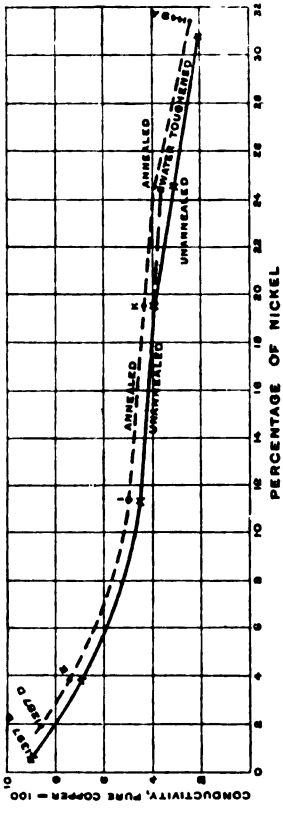
Prof. Barrett. Professor BARRETT desired to refer to the electrical and magnetic properties of the interesting series of alloys of nickel and iron which the Author had brought before the Institution. In March, 1895, the Author sent him the first batch of alloys for the purpose of investigating their electrical and magnetic properties, in continuance of an investigation which he had begun previously upon alloys of manganese steel. The investigation of some of the physical properties of these alloys he (Professor Barrett) had now carried on for nearly 4 years, in conjunction with the assistant physicist in the Royal College of Science, Dublin, Mr. W. Brown, B.Sc. For convenience of testing, the Author rolled, where feasible, the specimens into long, thin rods 106 centimetres long and ½ centimetre in diameter. The object of having them that length was for the purpose of making tests of the electrical conductivity, and also for the purpose of determining their magnetic permeability. It would have been better to have had wire for electrical measurement, but that was not feasible in all cases. The rods were made long and narrow so that in the method of testing the permeability the demagnetization produced by the poles might not interfere. In testing the conductivity they (*i.e.*, Mr. Brown and the speaker) used the potential method. As it was not possible to employ the ordinary method of measuring resistance, each of the samples was compared with a standard copper rod the conductivity of which had been carefully determined in Lord Kelvin's laboratory. They also compared them with a standard iron rod of the purest commercial iron which was turned true and of the same length. Particulars of the method of the experiments, and also of the mode of reducing the results would be given in a Paper now being published in the Transactions of the Royal Society of Dublin. Some of the results were shown in *Fig. 1*, from which it would appear that the thermal

*Fig. 1.*

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treatment was extremely important in every case after manufacture. In every case the annealed rods had a higher conductivity than the unannealed rods of whatever alloy, whether nickel, manganese, tungsten, or any other alloy. Table I showed the electrical conductivity of a selected series or samples of the nickel alloy. In the first column was given the maker's marks, in the next four columns the percentage of nickel and other elements (excluding iron) in these specimens; the iron present making up the total sum to 100. The electrical conductivity, compared with Matthiessen's pure copper as 100, was given in the next two columns, one

Prof. Barrett.

TABLE I.—ELECTRIC CONDUCTIVITY OF NICKEL-STEEL ALLOYS.

| Mark. | Analysis: per cent. of | | | | Conductivity, Copper = 100. | | Specific Resistance in Microhms per Cubic Centimetre (calculated) |
|---|---|---|---|---|---|---|---|
| | Ni. | C. | Mn. | Si. | Unannealed. | Annealed. | Unannealed. |
| 1,287 D . | 1·92 | 0·14 | 0·72 | 0·21 | 8·0 | 8·5 | 21·5 |
| 1,287 E . | 3·82 | 0·19 | 0·65 | 0·20 | 6·9 | 7·3 | 24·9 |
| 1,287 I . | 11·39 | 0·18 | 0·93 | 0·22 | 4·5 | 4·9 | 38·2 |
| 1,287 K . | 19·64 | 0·19 | 0·93 | 0·27 | 4·0 | 4·3 | 43·0 |
| 1,287 L . | 24·51 | 0·16 | 1 00 | 0·30 | 3·1 | 3·8 | 55·5 |
| 1,449 A . | 31·40 | 0·70 | 0·82 | .. | 2·0 | 2·4 | 86·0 |

being the unannealed specimens, and the other the annealed specimens, *i.e.*, specimens which had been raised to a temperature of about 1,000° C., and then allowed to cool in the annealing oven for 4 days and 4 nights. In the last column is given the specific resistance deduced from these conductivities. The addition of nickel alone was found to have much less effect in lowering the conductivity of iron than that of almost any other metal he had tried. In every case the conductivity was lower than that of pure iron. An increase of about 1·6 microhms for an increase of about 1 per cent. of nickel was generally found in the alloys he had tested. If, however, a small quantity of carbon, silicon, manganese, or aluminium were present, then a very large reduction of conductivity took place, and the addition of nickel to such a composite alloy made a very high resisting body. But when dealing with small percentages of nickel, such as from ½ per cent. to 1 per cent. of nickel, this metal had no bad effect on the conductivity. For example, Table II gave a sample with 1 per cent. of nickel and

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Prof. Barrett. 1 per cent. of manganese. The conductivity was 6·9 in the annealed condition and 7·0 in the unannealed state; leaving out

TABLE II.—EFFECT OF ADDING SMALL PERCENTAGE OF NICKEL TO A LOW MANGANESE STEEL.

| — | Analysis. | | | Conductivity, Copper = 100. | | Specific Resistance in Microhms (calculated). |
|---|---|---|---|---|---|---|
| | Ni. | C. | Mn. | Unannealed. | Annealed. | Unannealed. |
| 1,420 A . . . . | .. | 0·5 | 1·0 | 6·0 | 7·0 | 28·7 |
| 1,420 B . . . . | 1·0 | 0·5 | 1·0 | 6·9 | 7·0 | 24·9 |

the nickel the conductivity was a little less. So that actually the addition of a small quantity of nickel seemed to improve the conductivity of such an alloy containing a small percentage of manganese. But when a very much larger percentage of nickel was reached, one containing from 15 to 25 per cent. of nickel, then there was a very large decrease in the conductivity, and a very high resistance; and if to those large percentages of nickel a small percentage of manganese was added, as in the alloys shown in Table III, then there was an extraordinarily high

TABLE III.—SPECIFIC RESISTANCE AND TEMPERATURE COEFFICIENT OF NICKEL-MANGANESE STEELS (UNANNEALED WIRE).

| — | Analysis: per cent. of | | | Specific Resistance in Microhms per Cubic Centimetre. | Temperature Coefficients per Cent. per 1° C. |
|---|---|---|---|---|---|
| | C. | Ni. | Mn. | | |
| Best commercial iron | 0·03 | .. | .. | 10·47 | 0·623 |
| 1,420 B . . . . | 0·5 | 1·0 | 1·0 | 28·63 | 0·150 |
| 1,109 D . . . . | 0·6 | 14·5 | 5·0 | 83·11 | 0·109 |
| 1,414 A . . . . | 0·6 | 19·0 | 5·0 | 90·62 | 0·104 |
| 1,414 B . . . . | 0·6 | 25·0 | 5·0 | 97·52 | 0·085 |
| 1,449 A . . . . | 0·7 | 31·4 | 0·8 | 86·60 | 0·090 |

resisting material. The samples in this Table were all drawn into wire, and their specific resistance determined in microhms per cubic centimetre at 16° C., and their temperature coefficients were also determined. With 14·5 per cent. of nickel and 5 per cent. of manganese, the specific resistance was 83·1 microhms per cubic centimetre at 16°. The variation of resistance for increase of

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temperature per cent. for 1° C. was 0·109. For 19 per cent. of nickel and the same quantity of manganese, 5 per cent., there was an increase from 83 to 90·6 microhms, and rather a diminution of the temperature coefficient, 0·104. With an increase of nickel, from 19 to 25 per cent., with the same quantity of manganese, there was the extraordinary resistance of 97·5 microhms, with a lower coefficient temperature of 0·085. With 31 per cent. of nickel and diminishing the manganese to 0·8, then the resistance began to decrease. It might be perhaps worth mentioning that the particular alloy with 25 per cent. of nickel and 5 per cent. of manganese had the largest specific resistance of any metallic conductor which was yet known in commerce. It was nearly 60 times the resistance of pure copper, 10 times the resistance of pure iron, and Prof. Barrett.

TABLE IV.—MAGNETIC PROPERTIES OF NICKEL STEELS.

| Mark. | Per Cent. of Nickel. | Maximum Induction for H = 45 C.G.S. | Residual Magnetism in Terms of B. | Coercive Force in Terms of H. |
|---|---|---|---|---|
| Best commercial iron | .. | 17,480 | 7,120 | 1·66 |
| 1,287 D . . . . | 1·92 | 16,750 | 8,200 | 2·69 |
| „ E . . . . | 3·82 | 17,000 | 8,400 | 2·75 |
| „ I . . . . | 11·39 | 8,560 | 4,800 | 17·15 |
| „ K . . . . | 19·64 | 8,000 | 4,960 | 20·00 |
| „ K unannealed . | 19·64 | 5,950 | 3,900 | 24·38 |
| „ L . . . . | 24·51 | 4,460 | 2,820 | 22·90 |
| 1,449 A . . . . | 31·40 | 4,660 | 1,720 | 2·10 |

4½ times the resistance of German silver, and therefore he thought from a practical point of view it was an alloy of extremely great interest. It was easily worked, and a beautiful material. He now turned very briefly to the magnetic properties of those alloys. In order to determine the magnetic permeability, one of two methods was usually employed: either the ballistic method, where the material was made in a ring, or the so-called magneto-metric method, where a long thin rod of the material used was taken and its change in magnetism determined by the deflections of a magnetic needle. The magneto-metric method was very much more rapid and available for a much larger range of experiments, and consequently he adopted it. They had determined complete B and H curves, *i.e.*, the complete magnetic cycle for the whole of

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Prof. Barrett. the alloys of nickel together with 100 other alloys—a very laborious proceeding. Self-demagnetization was practically avoided by the length of the bar, being upwards of 200 times its diameter. The maximum magnetic field employed was 45 C.G.S. units. Every one of the samples was compared with the best commercial iron containing 0·02 per cent. of carbon. With this iron in a field of 45 C.G.S. units the maximum induction was 17,480, the retentivity was 7,000 and the coercive force 1·66, measured in terms of H. He drew special attention to the next two numbers. With 1·92 of nickel the maximum induction was almost the same (16,750) as that of pure iron. The retentivity was, however, greater (8,200), and the coercive force slightly greater (2·67). When the nickel was increased to 3·82 per cent. then the maximum induction, with the same magnetic field, was practically the same as with good iron (17,480). The retentivity was only slightly increased, and the coercive force was only slightly increased to 2·75; so that, in an electrical transformer, that sample of iron and nickel would practically use up as little energy, or almost as little energy, as pure iron. If the quantity of nickel was increased to 11·4 per cent., then a great drop took place in the maximum induction, *i.e.*, in the amount of magnetism that could be produced with the same magnetizing force. It fell to half the amount (8,560); a great drop in the retentivity occurred also (4,800), and a great increase in the coercive force also occurred, the amount now being 17·15. Increasing the nickel to nearly 20 per cent. there was not any very great change made. The induction was practically the same, the retentivity the same, and a little greater coercive force. The unannealed bar, as might be expected, had a greater retentivity and a greater coercive force. The coercive force of the 19 per cent. of nickel was the largest of any alloy of steel that they had yet examined, whether nickel or anything else. If the quantity of nickel was increased to 24 per cent., curiously the coercivity was diminished and the retentivity also fell. If the nickel were increased to 31 per cent. a great drop seemed to again occur. He should like to have some more samples to verify those statements, but there was apparently a sudden reversal in the curve. That accorded very well with the singular results that the Author obtained unknown to the speaker in the mechanical properties in the alloys of steel. The curious bend in the curve giving the tensile strength of the steels seemed to have its analogue in the corresponding change in the magnetic properties of the steel when

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that large percentage of nickel occurred. He might mention that Madame Curie had recently published an interesting Paper on the magnetic properties of a variety of alloys of iron, and the results of that lady physicist supported the conclusion to which he directed attention some years ago, viz., the very great importance, from a practical point of view, of exact physical determinations in the manufacture of steel and other alloys of iron. The sciences of civil and mechanical engineering were intimately connected with the properties of steel, and with regard to the mechanical as well as the magnetic properties of steel, the importance of the critical or hardening temperature of the steel, or, as he had called it, the recalescent point, was becoming increasingly recognized, *i.e.*, the particular temperature at which the steel lost its magnetism or regained it again on annealing. In fact, as a recent writer had stated, engineering was becoming the child of the singular properties of steel at its recalescent point, and that was a matter intimately connected with the present subject, but into which time would not now allow him to enter. Prof. Barrett.

Mr. DAVID CARNEGIE noticed that in the preparation of the Author's specimens, a bar, 2½ inches square and about 30 inches in length, was cast of each mixture; in the experiment the molten alloy was poured into a cast-iron mould. It would be of interest to know if in each cast the entire length of the bar was sound, or what proportion of it was sound, and if that proportion varied with the increase of nickel. It might also be of interest to know the conditions of the mould when the metal was poured into it, and the temperature to which it was heated, and if it was coated with composition. Annealing did not appear to have so great an influence as in other alloys; in fact, there was apparently little or none from the material within the comparatively brittle zone, that was, about 7 per cent. to 19 per cent. It would be helpful to know how the cast and forged specimens were annealed, to what temperature they were raised, and if the specimens were retained in the furnace at that temperature for any length of time; also, if in annealing the specimens they were cooled in the open air or in any medium to retard cooling, and if the Author had tried to anneal the specimens twice, or more often, and with what results. He should also like to call attention to another matter with reference to the forging of the small ingots. The Author stated that no special difficulty was met with in reducing the ingot, care being used during the heating process. One would like to know if it was necessary to vary the temperature of the heating furnace while Mr. Carnegie.



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Mr. Carnegie. the various ingots containing different percentages of nickel were heating, and if any observations were made during the heating process?

Prof. Beare. Professor HUDSON BEARE exhibited specimens which were fractured in repeated-bending tests of nickel-iron alloys he had made for the Author. The specimens were rotated at about 200 revolutions a minute. The specimens were in the condition of an overhung arch, and the load suspended at the end of the specimen was intended to produce a stress, calculated by the ordinary bending stresses theory, of about three-quarters or two-thirds of the tensile elastic limit as determined in the ordinary tensile machine. The results were shown in Table A. He only had one sample of each quality, except in the case of a 3-per-cent. nickel steel, where he had an annealed and an unannealed specimen, and there the difference in the result was very striking.

REPEATED BENDING TESTS OF NICKEL-IRON ALLOYS, ETC., IN SPECIAL REPEATED LOADS TESTING MACHINE.

| U. C. L. No. | Marks. | Material. | Tenacity. As given by Mr. Hadfield. | Limit. As given by Mr. Hadfield. | Calculated Stress per Square Inch in Repeated Load Machine. | Total Repetitions of Stress before Fracture. | Ratio $\frac{\text{Stress}}{\text{Limit}}$ |
|---|---|---|---|---|---|---|---|
| | | | Tons. | Tons. | | Revs. | |
| 3,853 | 2,415 F. | Hadfield's manganese steel . | 60 | 28 | 21·5 | 193,000 | 0·768 |
| 3,854 | 2,416 F. | 14 per cent. N, as forged . . | 54 | 22 | 16·6 | 184,000 | 0·75 |
| 3,855 | 2,417 F. | 10 per cent. N, unannealed . | 60 | 40 | 25·4 | 76,000 | 0·63 |
| 3,856 | 2,418 F. | Ordinary M. S., unannealed . | 38 | 24 | 11·7 | Still unbroken | 0·49 |
| 3,857 | 2,419 F. | Ordinary M. S., annealed . . | 38 | 24 | 17·5 | 53,000 | 0·73 |
| 3,858 | 2,420 F. | 3 per cent. N, annealed . . | 36 | 26 | 19·0 | 46,000 | 0·73 |
| 3,859 | 2,422 F. | 3 per cent. N, unannealed . | 36 | 26 | 18·9 | 20,000 | 0·73 |
| 3,860 | 2,444 F. | Very M. S., unannealed . . | 28–30 | 17 | 11·7 | 727,000 | 0·69 |
| | | *Some Tests of Ordinary Good Iron and Steel.* | | | | | |
| | | | Determined in Laboratory Testing Machine. | | | | |
| 3,436 | .. | L. W. R. O. M. S. . . . | 27·7 | 17·5 | 12·2 | 212,000 | 0·70 |
| 3,574 | .. | 1½-inch Bessemer machinery steel, planished . | 37·8 | 23·7 | 14·2 | 214,000 | 0·60 |
| 3,432 | .. | 1½ E. R. Wt. I. . | 23·5 | 15·2 | 13·8 | 203,000 | 0·90 |

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Prof. Beare.

The annealed specimen took 46,000 repetitions of the stress before fracture, while the unannealed only took 20,000. It was the same stress exactly, with the same load. He also exhibited specimens of the materials which were tested in the ordinary testing machine of the Laboratory. The experiments were not carried out by himself, but by Mr. de Segnndo, except in the case of one very remarkable specimen. The specimen was originally practically $\frac{3}{4}$ inch in diameter and 10 inches long; and it began to show a very slight permanent set, considerably less than $\frac{1}{1000}$ inch, at about 20,000 lbs. stress. The actual limit, what would be called the commercial limit, of elasticity was 46,400 lbs., and the greatest load carried was 107,300 lbs. The remarkable point about the test was the extraordinary elongation, which was 53·4 per cent.; so that a bar, originally 10 inches, stretched to over 15 inches in length, and with absolute uniformity from end to end. There was hardly any drawing down at the fractured point, the elongation at the fracture only being 66 per cent. as compared with 53 per cent. for the whole bar, the reduction being exactly 50 per cent. The results obtained by Mr. de Segundo in his pure tensile tests were given in the Table below:—

| Bar Number. | Material. | Tensile Stress in Lbs. per Square Inch. | | | | Extension at Fracture on Whole Length of 18 inches. |
|---|---|---|---|---|---|---|
| | | When Permanent Set began. | When Set was $\frac{1}{10,000}$. | Commercial Limit of Elasticity. | Fracture Load. | |
| | | | | | | Per cent. |
| 2,430 F. | .. | 38,000 | 44,000 | 72,000 | 152,860 | .. |
| 2,404 F. | .. | 17,000 | 22,000 | 51,000 | 116,550 | 59·0 |
| 2,440 F. | .. | 20,000? | .. | 62,000 | 84,750 | Not measurable; welding very bad, and fracture very irregular. |
| 2,425 F. | .. | 35,000 | 45,000 | .. | .. | |

Sir W. H. White.

Sir W. H. White, K.C.B., Vice-President, thought the Institution was to be congratulated on the fact that the Author had chosen its Proceedings as the place of publication of the Paper, which was one of a long series of most valuable monographs which he had prepared upon the qualities of alloys of iron and other of the less common metals. With regard to that particular Paper there could be no doubt that it afforded food for very thorough and careful study. He had looked the Paper through so far as was possible in the time at his disposal, and although he thought he had a fairly complete acquaintance with what had



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Sir W. H. White. been written in regard to the alloys of iron and nickel, he was bound to say that he found in the Paper not merely a very generous appreciation of the work that had been done by other experimentalists, but a remarkable series of additions to the results. He had never seen so clearly before the very singular variations in the mechanical qualities which occurred with increase in the percentage of nickel. The Author was careful to point out that his experiments referred to only one phase of the question, and even that had so many features in it that it covered a very large ground. But, taking the limitations that the Author had imposed upon himself, it appeared to him that the facts he had put before the engineering profession in regard to the choice of alloys, and the occurrence of a phase of brittleness, the information he had given as to corrosion of the alloys of nickel and iron, and the whole of the facts he had put before the Institution as to the manufacture of nickel, and the sources of supply—all those things taken together, made the Paper one of the most extreme value. There were certain points in the Paper with which he had close personal acquaintance on which he would like to say a word or two. In regard to the use of nickel in armour the Author remarked that some people were inclined to suppose that with certain qualities of armour nickel could be dispensed with without sacrificing protective capability. That was not a mere speculative opinion. It was the result of a very careful series of experiments, and it had, at one time, a very marked effect upon the cost of production of armour, for at that time nickel was not quite so cheap as it was at present, and the addition of 1 per cent. of nickel to armour made a very sensible increase in price per ton. But what he wished to state particularly was that the action which was taken was based, not upon any absurd idea of economy, but upon the results of very careful and methodic experiments. At the present time they were accustomed to hear of nickel-steel armour as achieving the remarkable advances which had been made. As a matter of fact those who were familiar with the manufacture knew that, while nickel played a very prominent part, there were other materials in the armour of which less was said, but which were perhaps equally influential. He was not there, of course, to reveal the secrets of armour-plate manufacturers, but the Author would bear him out in saying that nickel, having passed through a period perhaps of some doubt, was now enjoying a reputation which was not altogether deserved. The Author—with his natural admiration for a material which possessed such splendid

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working qualities, and no doubt with painful memories of that intractable child of his, manganese steel—was, he thought, in one or two places in his Paper inclined to give nickel steel a credit which it hardly deserved. For example, the Author referred to the trip of the United States armour-clad "Oregon," which came round from the Pacific to the West Indies during the War, as possibly having been made so great a success as it was because she had nickel-steel shafts. Anyone who would read the American official reports of that voyage would know that there was no period during the voyage when any particular stress was put upon any part of the shafting. Whether it was nickel steel or not, the development of power was very moderate, although the speed averaged was good, but not high; and the great feature of the performance was the successful passage of a ship of that class over such a long voyage at such short notice, and her arrival in the West Indies in a thoroughly efficient condition. There was one omission which he thought the Author had made, and a rather important one, in the use of nickel steel. Ever since nickel steel became a marketable commodity, its possible employment in the structures of ships had been very carefully watched, and at the present time there was a considerable quantity of steel, which might be nickel steel or might not, but which had the mechanical properties of nickel steel. He was one of those who thought that an engineer should specify the mechanical properties of his material and should not concern himself deeply with the chemical composition. That might be wrong, but that was his idea. His method usually was to specify the strength, the ductility and the working qualities he wanted, and if the metallurgists liked to make it of gold and did not charge him for it, he should not blame them. At the present time, as he said, nickel steel was being used not merely in destroyers and light vessels, where steel of high strength was being employed with very great success, but in much larger vessels. He would like to say, merely as a reminiscence, that about the year 1876, in conjunction with Mr. James Riley, who was then the Works Manager of the Landore Steel Works, he had to do with a series of tests of steel varying between 35 and 40 tons to the square inch in ultimate strength, which was built into a representation of a portion of a ship. It was riveted up with steel rivets of the same quality and subjected to a series of the most tremendous percussive tests, with thoroughly satisfactory results. He believed he had already mentioned it many years ago in the course of a discussion at the Institution, but he would like again to recall the fact that even at that early

Sir W. H. White.

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Sir W. H. White. time of steel manufacture, it was possible to produce steel that fulfilled something like the conditions that were now obtained in a better form and with better working qualities by the free use of nickel. He would end as he began by saying that he, for one, considered the Paper a most valuable addition to the series.

Mr. Brough. Mr. BENNETT H. BROUGH noticed that among the nickel minerals enumerated in the Paper the Author included sulphides said to have been discovered by Mr. Emmens in 1892. It had been clearly shown by Mr. S. L. Penfield that these minerals could not be regarded as distinct species; indeed, little dependence could be placed on formulas deduced from analyses of minerals of such doubtful purity, especially where a chief constituent was determined by difference. In his interesting account of the early history of nickel, the Author stated that the earliest English reference to nickel was in a work published in 1741; but the quaint quotations given in the Appendix showed that the descriptions related to the ore and not to the metal. It might, perhaps, have been added, that the work quoted was a translation from the Latin original published at Leyden in Holland in 1739, the Author, Johann Andreas Cramer, being a native of Saxony.

Mr. Charleton. Mr. A. G. CHARLETON desired to refer to some interesting observations made, by a Canadian engineer, Mr. McCharles, relative to the geological occurrence of nickel in the deposits at Sudbury. The workable ore-bodies did not as a rule occur in the large areas of "diorite" which were found in the district, but rather in the tongues which seemed to shoot out from them. These tongues were often extremely narrow, in some cases scarcely wider than the mineral outcrop. Mr. McCharles also noted that there was one very important difference in the surface conditions of deep permanent mines and mere pockets of ore, very seldom noticed by engineers who had visited the district, viz., that with few exceptions the big ore-bodies were of lower grade than those which were of medium or small size, other things being equal, the latter were generally the more valuable mines. He further observed that gold, platinum, and other by-products of these nickel mines were carried as a rule not by the pyrrhotite, but by the copper-pyrites which the deposit contained.

Mr. Sharp. Mr. ARCHIBALD SHARP remarked that the curves showing the temperatures at the points of recalescence, Plate 2, were drawn with the time as abscissas and the temperatures as ordinates. While the temperature seemed to decrease steadily the time seemed to go backwards at various points. He should like to know whether that was a draughtsman's error or the realization of

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the time machine that Mr. Wells the novelist had recently imagined. Mr. Sharp.

The PRESIDENT said, before calling on Mr. Hadfield to reply, he desired to convey the thanks of the Institution to Professor Barrett for coming from Dublin to favour the members with his remarks that evening. He was sorry Professor Barrett could not be allowed to illustrate his remarks by lantern-slides, but the Institution had learned by experience that, however beautiful the slides might be, their impression on the mind was evanescent, and when the discussion took place there was no diagram, or anything before the speaker, to refer to an error he might have observed, or a point on which he required further observations. The Institution had been forced by circumstances to lay down the law that in the discussions slides should not be used, although the members were always pleased to see slides used to illustrate particular features of the Papers. The points that Professor Barrett had raised supplementary to the remarks by Mr. Hadfield were most important, in that they showed how, by electrical and magnetical appliances, the very innermost being of materials could be searched. Those who were in the habit of measuring electrically the conductivity of materials, or the permeability of magnetical matter, had supplied to them in some way a mental gift which enabled the searcher to see right into the play of the molecules. Professor Barrett was himself the discoverer of one great critical point in iron and steel, the point of recalescence. He was able to show that at that particular point there was a certain change in the attitude of the molecules and atoms, which showed that work was given out, and that something had occurred which altered the whole structure of the material. That had been the commencement of a great research into the crystallization of matter, and into the various chemical and physical changes in the state of matter under the influence of temperature and pressure. The President.

Mr. R. A. HADFIELD, in reply, thanked the members for the cordial vote of thanks they passed. It had been a great pleasure to present the Paper to the Institution. He had presented a Paper some years ago on another series of alloys, and had obtained so much information from the discussion that he thought he could not do better than present the particular research regarding the alloys of nickel and iron. It had involved a very large number of experiments, and naturally whilst one could not get everything as exact as would be liked, he thought, on the whole, the tensile strength and the elongation of the Mr. Hadfield.

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Mr. Hadfield. material would be found to correspond very closely with the products if produced commercially. In a research of this kind there was bound to be a certain number of variations, but he thought the curves brought out the variations of the different percentages of nickel in a very remarkable and clear manner. He noticed in the technical press that some reference had been made with regard to the abstract of his Paper, and it was stated that he believed a steel propeller shaft was not so good as a wrought-iron one. With Sir William White present he would not like it to be thought that he believed that for one moment. He believed wrought iron was an excellent material, but as a steel maker he certainly could not believe in wrought iron displacing steel at the present day. He was obliged to his friend Professor Arnold for the very able way in which he had expressed his opinion on the research work. Professor Arnold was good enough to describe a particularly brittle percentage of nickel, which the Author had discovered, viz., a 12 per cent. alloy, as a "critical point." He thought this was an excellent term with which to describe that curious mixture. Professor Arnold's own results were obtained at the Steel Works of the University College, Sheffield. He believed it was the only University College in the world to which Steel Works were attached, and they were very proud of them. With regard to Mr. Snelus's remarks on occluded gases, he was quite correct. Nickel steel had to be watched in that respect very carefully, and some of the earlier difficulties that were met with in producing nickel-iron alloys arose, he thought, from the existence of that defect. Professor Arnold was wise enough to take his nickel and remelt it, and consequently he got rid of a great deal of the oxygen present. It was that which enabled him to get such a remarkable set of specimens as those before the meeting. There was one specimen which Mr. Hadfield confessed frankly excelled his own specimen of the same percentage, viz., a material containing 12 per cent. of nickel, which almost bent double cold. It was a very remarkable product, seeing that the same material had a tenacity of nearly 90 tons per square inch. He thought Sir William White would agree that that was a very remarkable result. His own series of alloys contained a certain amount of manganese, and the influence of even 1 per cent. of manganese was considerable. Professor Barrett had noted this point in his electrical experiments. Professor Unwin made a most interesting contribution to the discussion. He commenced by saying that he did not know whether the Author had referred to Sir William Fairbairn's

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Mr. Hadfield.

experiments, but these were described on page 64. Professor Unwin had referred to the compression-tests, shown in Fig. 6, and as to whether they were of use as a means for determining hardness. He certainly had not that object in view at all. His object in carrying out compression-tests was that it gave one a knowledge of certain characteristics which could not be acquired by either tensile or bending tests, but they were certainly not made with the idea of determining the hardness. They were to some extent comparable, but he should not like for one moment to quote them as proof of his own opinion as to the hardness produced by the various increasing additions. Then, referring to the 12 per cent. alloy, it certainly was a remarkable fact that the critical point of hardness noticed was 12 per cent. Why this particular percentage of nickel should produce that hardness he confessed he was quite unable to explain as far as his own experiments went. As Professor Unwin pointed out, nickel does increase very much the elastic limit, which was a very important point. By the addition of nickel a steel was obtained with high elastic limit, and without quenching. Of course, high tenacity could be obtained by quenching mild or medium steel, but he thought such steel was much more liable to internal stresses, which, of course, it was very desirable to avoid. One of the speakers had spoken of corrosion, and he rather gathered from his remarks that that gentleman's opinion was that nickel steel was less subject to corrosion. But that was not so. Nickel steel might at first resist corrosive effect much longer than ordinary steel, but in the end he did not think it would be found superior to ordinary carbon steel. He was very glad indeed to see his friend Professor Barrett present. He had worked very long and laboriously with a most extraordinary series of alloys which he, the Author, had presented to him from time to time. Occasionally there had been a gap in the series, and letters had at once come to hand saying, "I must have that series made up"; and the reply went back, "It is impossible to roll the material." Then another letter had come, "You must manage it somehow." He was glad to say that on the whole the various series of alloys had been completed, and he hoped that Professor Barrett would be able to present a Paper to this or some other Society on the result of his work before long. Professor Barrett had pointed out how important the question of determining accurately the thermal treatment was. He quite agreed with that, and thought those who were engaged in the manufacture of armour-plates, for example, were finding out the benefit of using heat-determining apparatus such as the Le Chatelier

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Mr. Hadfield. pyrometer. Mr. Carnegie had asked some questions regarding the manufacture of the specimens. The size of the ingot was about 2½ inches square, and, as a rule, a certain amount had to be "topped," that is, the upper portion of the ingot, perhaps one-third of it. Nickel did not in itself confer soundness. That might naturally be expected, seeing how it occluded oxygen; so that one had to use either aluminium or silicon to obtain the necessary soundness, and consequently the piping so produced had to be removed. There was no secret or any special treatment necessary. Anyone able to make ordinary steel would be able to make nickel steel if ordinary care was taken. With regard to the condition of the mould, it was what was termed in Sheffield an ordinary crucible-steel ingot mould. It was smoked by means of carbon deposit to prevent the ingot itself adhering to the mould; but there was nothing special in any way as regarded its treatment. With regard to the effect of annealing he was glad to know that Professor Arnold fully confirmed his own experience that annealing did not seriously affect either the elastic limit or the tenacity. He thought Mr. Carnegie would find that to be so. With regard to the annealing of the specimens, they were placed in an ordinary annealing furnace, and annealed for about three or four days. The temperature reached would be about 1,800° F. They were allowed to cool slowly in the furnace and were not taken out of the furnace whilst hot. With regard to the forging temperature, that in the same way was very much like that used in treating ordinary carbon steel. He was specially glad that Professor Hudson Beare had referred to the interesting experiments made by himself and Mr. de Segundo. It might interest members to know that the very extraordinary specimen, having an elongation of about 50 per cent. and a breaking load of about 60 tons to the square inch, was made up of the manganese iron alloy containing 5 per cent. of manganese and the brittle nickel iron alloy (12 per cent. Ni). He had specimens from the casting which he should be glad to show any members who were interested, and it would be seen how easy it was to crush the samples, in fact, almost as if they were sandstone. He had also a specimen of the brittle or critical percentage of nickel, and, strange to say, if the two were put together the extraordinary result was obtained that was seen in the test-bar. It certainly made it very puzzling to know how to explain such an extraordinary result as that. Sir William White had referred to the question of the "Oregon" shaft. He, the Author, was glad that he put at the end of his remarks a note

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of interrogation, for he had received a letter from a friend in America who was connected with the Bethlehem Works, where the shaft was made, and from it he was pleased to see that carbon steel could still retain the credit, because the shaft was made of carbon steel. Sir William White was so well able to deal with that particular aspect of the case that he only suggested the use of nickel steel for that purpose, because he believed the Americans were going ahead very much in the use of this material. In England engineers were now more carefully considering the question and also going ahead, but he thought the Americans were the first to take up nickel steel in a large way. He had on the Table a very interesting result of one of the first applications of nickel steel by Messrs. Schneider, who were kind enough to send him a photograph showing a nickel-steel plate which he believed was the first large armour-plate of the kind, and which was tested in 1890. He believed the percentage of nickel in it was about 3. With regard to Mr. Brough's remarks, he regretted if there had been any mistake in the quotation, but his own copy, from which he took the information, was published in English, and he understood it was an English publication. Those who read it would see that there were such clear references to this country that it seemed an entirely English publication. It was dedicated to an Englishman and printed in the "Half Moon between the Temple Gate," which he presumed was in London—at that time, at any rate. In reply to Mr. Sharp, the heating and cooling curves were given in the manner usually adopted by Mr. Osmond, that is in Plate 2, Figs. 1 to 6, the intervals of time were represented by ordinates and the temperatures by abscissas. Each degree of the pyrometer scale represented 10° C. Full information regarding Mr. Osmond's methods would be found in his Paper "On the Critical Points of Iron and Steel."[1] He again expressed his thanks for the cordial way in which the members had received the Paper. Mr. Hadfield.

[1] Journal of the Iron and Steel Institute, 1890, Part 1.

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## Correspondence.

Mr. Ashton. Mr. H. T. ASHTON observed, in reference to the Author's statement that "nickel does not show any disposition to segregate in steel like other elements," that photo-micrographs to 150 diameters of the untreated steel from a gun liner tube, recently used in the Royal Gun Factory, containing 3·27 per cent. nickel, 0·24 carbon, 0·72 manganese, with a little silicon and traces of other elements, prepared for him by Mr. R. J. Redding, F.C.S., of the Royal Laboratory, Woolwich, showed a distinct segregation in parallel layers, the structure on the polished specimen being visible also with the naked eye. He had not seen any recorded observations of a similar structure in carbon steels; it was therefore probably due to the nickel contents of the steel; the effects of segregation were almost completely invisible after the steel had been oil-hardened at 785° C. and annealed at 480° C. In samples of chrome-nickel steels which have been similarly examined, a segregation had also been observed, but of a less regular type.

Mr. Browne. Mr. DAVID H. BROWNE, of Cleveland, Ohio, observed that the Author's results tended to show that nickel steel differed from other alloys in possessing an unusually high elastic limit and tensile strength, without at the same time showing hardness or brittleness, which was usually associated with high mechanical properties. The usual methods of testing metals were empirical; the amount of load necessary to cause deformation, and the further amount necessary to cause rupture, were determined, as well as the amount of deformation produced. Without doubting the value of such data, the usefulness of a metal depended more on its capacity for normal loads than on its behaviour under abnormal conditions. The life of a metal under normal strains he considered of more practical value as a test than determinations of breaking strain or elastic limit. At the Pope Tube Works in Hartford, Connecticut, and at the Bethlehem Iron Company's shops, in Bethlehem, Pennsylvania, many elaborate tests had been made to determine the "live strength," or working capacity of metals. The apparatus used might be described as a common lathe, with ball and socket chuck, and a rotary collar in the tail-stock. The tube or bar to be tested was fastened at one end in the chuck and the other end supported by the collar in the tail-stock, while from a roller-bearing ring, which encircles the tube or rod at its middle, depended

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an adjustable weight. On rotating the test-piece, the stress of this weight was applied to the alternate sides of the metal, and by adjusting the load so as to subject the test-piece to a strain much below its elastic limit a very close imitation could be produced of the strains to which steel was subjected in actual use as a shaft or axle. A 0·10 per cent. carbon-steel tube loaded to two-thirds its elastic limit would stand about 100,000 revolutions before breaking; under similar conditions and with loads two-thirds of the elastic limit, a 0·25 per cent. carbon-steel tube would stand about 200,000; a 0·50 carbon tube about 400,000, and a nickel-steel bicycle tube (0·25 carbon, 5 per cent. Ni) in the neighbourhood of a million revolutions. A test made in the usual manner would show that a 0·25 per cent. carbon steel, without nickel, had an elastic limit of 40,000 lbs., and a tensile strength of 70,000 lbs., while a steel containing 0·25 per cent. carbon, with 5 per cent. nickel has 60,000 lbs. elastic limit and 95,000 lbs. tensile strength. In other words, while nickel steel would show, under unusual loads, from 40 to 50 per cent. greater strength than simple steel, it would withstand normal strains about five times as long as simple steel of the same carbon. In actual work the resistance to normal and continuous strain and not the resistance to extraordinary and sudden shock determined the value of any given material. The Author's work tended to confirm the opinion that nickel steel was homogeneous. If molten steel be considered as a magma, holding various elements in solution, it was evident that those elements which settled out and formed foreign particles in the cooled metal would produce weakness, while those which remained chemically combined with the iron might prove harmless or even beneficial. That nickel united with iron in various proportions to form definite crystals had been suspected by Guillaume and others. In 1892, Mr. Browne described in the "Journal of Analytical and Applied Chemistry," the discovery in matte of crystals having the composition $Fe_8Ni_9$. These crystals resembled small corner cuttings of thin tin foil, and varied from a few lines to perhaps half an inch on the longest side. The form was universally that of a right-angled isosceles triangle. The crystals were very flexible and malleable, and appeared to be rather soft. This proved that nickel formed at least one definite chemical compound with iron, and the presumption that it formed others was very strong. That nickel steel formed a homogeneous compound seemed indicated by many evidences. The diminished segregation of nickel steel ingots, the lessened tendency to crack under hammer or rolls, the cleanness of edge left by a cutting

Mr. Browne.

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Mr. Browne. shears, the uniformity of micro-structure, and the seemingly paradoxical union of great strength with softness and ductility, all pointed to the conclusion that nickel and iron united to form definite compounds whose properties differed notably from those of the constituent metals. The Author's samples had all been made of very low carbon steel. If the increase in strength of any given sample over the sample next below it be divided by the percentage of nickel which produced the increase, a factor was obtained which might be considered as the gain due to 1 per cent. nickel added at that point. In the Author's sample F, 3·82 per cent. Ni, the gain due to 1 per cent. nickel was 4,392 lbs. per square inch on both elastic limit and ultimate strength. Mr. Browne found remarkable unanimity in the reports of various investigators on this point. Rudeloff, working on low carbons, found the gain due to small amounts of nickel equal to 5,090 lbs. on the elastic and 3,469 lbs. square inch on tensile strength for each 1 per cent. added nickel. Mr. Beardmore's samples showed on low carbons a gain of 5,485 lbs. on elastic, and 3,509 lbs. on tensile. The Canadian Copper Company had found on soft boiler steel a gain of 4,384 lbs. elastic, and 3,514 lbs. tensile for each 1 per cent. nickel added. With higher percentages of carbon the increase in strength due to nickel was more marked. Comparing in each case a nickel steel with a similar steel of identical composition, except for nickel, Mr. Browne found the following factors:—

| — | Elastic. | Tensile. |
|---|---|---|
| | Lbs. | Lbs. |
| Average of all soft low-carbon steels show a gain due to 1 per cent. Ni of about . . . . . | 5,000 | 4,000 |
| Bethlehem Iron Company oil-tempered, annealed forgings, 20 C, 3½ Ni, gain due to 1 per cent. Ni . | 5,714 | 8,571 |
| Ditto, 30 C, 3½ Ni, show a gain due to 1 per cent. Ni of | 6,571 | 5,714 |
| Ditto, 40 C, 3½ per cent. Ni . . . . . | 8,285 | 7,142 |
| Ditto, 50 C, 3½ Ni . . . . . | 10,570 | 8,571 |
| Crescent tool steel, 1·10 C, 1·65 Ni . . . . . | 18,957 | 20,484 |

These figures showed a remarkable curve of increase in strength on elastic limit due to 1 per cent. nickel with rising percentage of carbon. The increase in strength brought about by nickel was not necessarily accompanied by a loss in elongation. Nickel steel was exceedingly sensitive to heat treatment, but if annealed at the proper temperature it possessed a wonderful ductility in conjunction with high tensile strength. One point to be remembered in handling nickel steel was that its recalescent point was lower than simple carbon steel. Mr. Souther, of the Pope Tube

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Company, had stated that the recalescent point of 25 carbon steel was 1,600° F.; that of 50 carbon steel was from 1,350° F. to 1,400° F.; while that of 25 carbon steel, 5 per cent. nickel steel was about 1,080° F. According to Mr. Ellis, the managing director of John Brown & Co. of Sheffield, the presence of nickel caused steel to crystallize at a much lower temperature than it would otherwise. This statement, in connection with Mr. Souther's determination of the recalescent point, showed the necessity for annealing nickel steel carefully, and at a comparatively low temperature, in order to obtain the best results. The peculiarity possessed by nickel steel of high resistance to tensile stress, combined with softness before the file, had been often noticed. Gun-barrels, containing 4½ per cent. nickel and 0·30 per cent. carbon, could be cut with a knife, and yet they showed 80,000 lbs. elastic limit and 105,000 lbs. tensile strength, with an elongation of 25 per cent. and contraction of area from 45 to 50 per cent. This high tensile strength could be attained in simple steel by the use of about 0·70 per cent. carbon, but at the expense of hardness and brittleness not shown in nickel steel. Nickel affected the hardness of steel, not by its influence *per se*, but by its action on the carbon present, which it seemed to throw into the so-called hardening condition. Colour carbon tests of nickel steel showed lower carbon than combustion tests, and this appeared to be due, not to any masking of colour by the nickel present, but to an actual passage of part of the carbon into a condition in which it gave no colour with nitric acid. The effect of carbon on the hardening of nickel steel depended on the amount of nickel present. With 6 per cent. nickel the steel could be quenched and tempered like an ordinary carbon steel. If the nickel were over 8 per cent. or 10 per cent. the carbon was not readily affected by heat treatment. An 18 per cent. nickel steel seemed to be as hard with 30 per cent. carbon as with 70 per cent., and this steel softened perceptibly on quenching. A 25 per cent. nickel steel was very much softened by quenching; 30 per cent. nickel caused most of the carbon present to assume the form of graphite. From these data it would seem that small amounts of nickel tended to throw the carbon into the hardening condition where it was very sensitive to heating or cooling, while larger amounts threw the carbon into the graphite state where it had little effect on the temper of the metal.

Mr. Browne.

Dr. J. A. FLEMING communicated the results of investigations on the electric and magnetic qualities of specimens of alloys kindly furnished by the Author. First as regarded the electric resistivity of pure nickel. In conducting some years ago a

Dr. Fleming.

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Dr. Fleming. research in conjunction with Professor Dewar on the electric resistance of metals and alloys at very low temperature, the greatest difficulty had been experienced in obtaining chemically pure nickel which would draw into wire and so enable an independent determination to be made of its absolute resistivity. The only nickel which at that time could be obtained of known purity was that produced by reducing the nickel-carbonyl prepared by Dr. Ludwig Mond. This nickel, however, was so brittle that it could not be drawn into wire, and it was feared that any attempt to melt it would introduce into it impurities. Hence, the only experiments made on the electrical resistance of this pure nickel were to determine its relative electric resistances at various temperatures between − 200° C. and + 200° C. The results were reduced by adopting the value given by Matthiessen for the electric resistivity at 0° C. of nickel, viz., 12,323 C.G.S. units at 0° C., and the resistivity at other temperatures was calculated in C.G.S. values from this number, and the observed ratios of the resistivity of the Mond nickel at various temperatures. Some time after the publication of these results he had received from Mr. J. W. Swan a sample of nickel electrolytically prepared, which was characterised by its remarkable softness, and being in the form of a regular wire its absolute resistivity could be determined.

On making the measurements he had been surprised to find that it gave a value for the resistivity of nickel at 0° C., not much more than half the value given by Matthiessen. This astonishing result showed that there was room for much additional research before the true electrical resistivity of pure soft annealed nickel could be stated. He had made many observations on the effect of very low temperatures on certain of the nickel-iron alloys, particularly the 19 per cent. nickel alloy. This alloy and others of similar composition was characterised by the peculiar property of being able to exist in different physical states at the same ordinary temperatures, depending upon whether it had been brought up to the ordinary temperature after cooling to very low temperatures or had been cooled to ordinary temperatures after having been heated red hot. In the first case it had a higher magnetic permeability and a less electrical resistivity than in the latter case. Also in the former state it was more brittle than in the latter. Its thermo-electric powers and resistivity temperature coefficients in the two states were quite different. He mentioned that a very pretty experiment could be shown illustrating the above fact with a loop of wire made of the 19 per cent. nickel-iron

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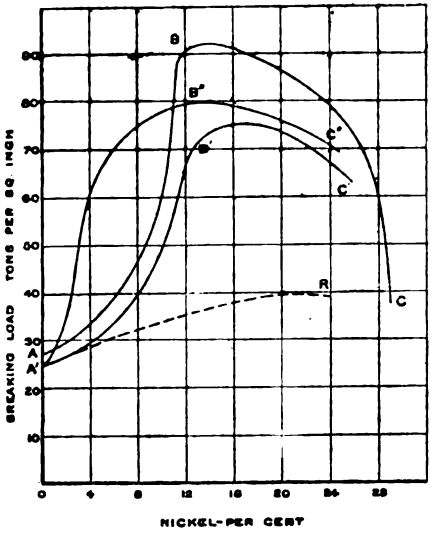
alloy. If one half of a previously heated wire was dipped in liquid air and then the whole wire allowed to return again to the ordinary temperature, and if a strong electric current was finally passed through the wire, it would be found that half of the wire which had not been dipped in liquid air became red hot before the remainder. This was a consequence of the fact that the resistivity of the half of the wire not so dipped was greater than that of the part which had been immersed. He felt sure that a careful and extensive examination of the properties of the nickel-iron alloys was likely to lead to a great extension of knowledge of magnetic phenomena. Dr. Fleming.

Mr. F. OSMOND, of Paris, remarked that the results obtained by the Author did not seem to be easily reconciled with the exclusive functions attributed by him to carbon in the physical properties of steel. The alloys studied contained on an average 0·17 per cent. of carbon and 0·83 per cent. of manganese. These quantities were certainly far from being negligibly small, but was their presence sufficient to explain the facts? To show that the answer must be in the negative, it was sufficient to compare the Author's results with those obtained by the "Fonderies, Forges et Acieries de St. Etienne,"[1] on similar alloys containing only 0·09 per cent. of carbon and 0·04 per cent. of manganese. (See the Table.) Plotting the Author's results, and those of St. Etienne on annealed test-pieces, and taking as abscissas the percentages of nickel, and for ordinates the breaking loads, *Fig.* 2 was obtained. The interval between the two curves A B C and A′ B′ C′ was a measure of the influence of the 0·08 per cent. of carbon and Mr. Osmond.

*Fig.* 2.




[1] Pamphlet published during the Lyons Exhibition, 1894, S. Kirsch, 6 rue de la Bourse, Saint Etienne.



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Mr. Osmond.

| Series A. Nickel varying from 2·50 to 25·00 per cent.; other elements as small as possible. | | | | | | Series C. Nickel constant = 15 per cent. Carbon varying from 0·10 per cent. to 1·00 per cent. | | | Series D. Nickel constant = 25 per cent. Carbon varying from 0·10 per cent. to 1·00 per cent. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical Composition. | | | Breaking Load. | | Increase of Breaking Load due to Hardening. | Reheated to dull Cherry-Red, and Cooled in Sand. | | | Reheated to dull Cherry-Red, and Cooled in Sand. | | |
| | | | | | | Chemical Composition. | | Breaking Load. | Chemical Composition. | | Breaking Load. |
| C. | Mn. | Ni. | Reheated to dull Cherry-Red, and Cooled in Sand. | Hardened in Water at dull Cherry-Red Heat. | | C. | Mn. | | C. | Mn. | |
| Per cent. | Per cent. | Per cent. | Tons per Sq. In. | Tons per Sq. In. | Per cent. | Per cent. | Per cent. | Tons per Sq. In. | Per cent. | Per cent. | Tons per Sq. In. |
| 0·10 | 0·04 | 2·48 | 27·3 | 37·9 | 38·8 | 0·06 | 0·02 | 73·0 | 0·05 | .. | 66·2 |
| 0·09 | 0·04 | 5·03 | 32·1 | 67·5 | 110·5 | 0·12 | 0·04 | 86·0 | 0·12 | 0·02 | 65·9 |
| 0·09 | 0·04 | 7·54 | 38·1 | 77·5 | 103·3 | 0·19 | 0·06 | 93·3 | 0·18 | 0·03 | 49·8 |
| 0·08 | 0·04 | 10·06 | 48·9 | 76·5 | 56·5 | 0·27 | 0·03 | 95·4 | 0·26 | 0·04 | 41·8 |
| 0·09 | 0·04 | 12·42 | 69·7 | 79·1 | 13·5 | 0·38 | 0·03 | 90·8 | 0·34 | 0·04 | 42·7 |
| 0·08 | 0·04 | 15·09 | 75·3 | 80·0 | 6·2 | 0·50 | 0·05 | 86·6 | 0·43 | 0·05 | 45·3 |
| 0·08 | 0·04 | 17·60 | 75·6 | 78·0 | 3·1 | 0·58 | 0·06 | 78·4 | 0·52 | 0·06 | 48·1 |
| 0·09 | 0·04 | 19·96 | 73·3 | 76·6 | 4·5 | 0·64 | 0·06 | 54·5 | 0·61 | 0·06 | 46·0 |
| 0·09 | 0·04 | 22·63 | 71·3 | 73·5 | 3·0 | 0·75 | 0·05 | 50·5 | 0·72 | 0·06 | 45·6 |
| 0·10 | 0·04 | 25·15 | 65·0 | 71·5 | 10·0 | 0·86 | 0·05 | 45·8 | 0·83 | 0·07 | 43·9 |

0·79 per cent. of manganese which separated the two series of tests. An approximate estimate might thus be formed of the additional diminution of strength which would accompany the entire elimination of the carbon and manganese in the St. Etienne alloys, and it appeared difficult to avoid the conclusion that the direct action of pure nickel on pure iron must be considerable. If nickel did not act on iron except by the intervention of carbon, the following facts must still be explained:—(1) In the St. Etienne series A, Table I, in which the percentages of carbon and manganese remained constant, why did water-quenching produce respective increases of the breaking load of 38·8 per cent. (2·48 of Ni), 110·5 per cent. (5·03 of Ni), 103·3 per cent. (7·54 of Ni), 56·5 per cent. (10·06 of Ni) as compared with the annealed specimens, while the increases became almost nil as nickel was over 13 per cent.? (2) In the

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St. Etienne series C, in which the nickel remained constant at 15 per cent. while the carbon varied, why did the breaking load rise from 73 tons to 95·4 tons per square inch as the carbon increased from 0·06 per cent. to 0·27 per cent., and why did it descend from 95·4 tons to 45·8 tons per square inch, while the carbon still increased from 0·27 per cent. to 0·86 per cent.? (3) In the St. Etienne series D, in which the nickel remained constant at 25 per cent. while the carbon varied, why did the breaking load rapidly decrease as the carbon increases from 0·05 per cent. to 0·18 per cent., and why did it remain practically constant as the carbon still increased to 0·83 per cent.? (4) Why was the magnetic induction of the Author's specimens I, K, L (Fig. 8, Plate 1) so much less than that of the specimens B, D, E, whatever be the intensity of the field? These were embarrassing facts for those who would believe that the metallurgy of steel depended merely on the contained carbon; they might not be surprising, however, from another point of view. Carbon, manganese, nickel, and the rapidity of cooling, joined together to lower, each with its particular activity, the points of transformation of the iron. While the transformations took place at temperatures higher than 400° C. they were nearly complete, and the effect produced was feeble. When the transformations took place at temperatures lower than 400° C., they became more incomplete as ordinary temperatures were approached; the steel was hardened whatever be the method of cooling. Lastly, steels which were not transformed at ordinary temperatures possessed a characteristic combination of strength and plasticity. It resulted that the steels H, I, K, L, M, of the Hadfield series, were self-hardening. The proofs were direct and numerous; their great breaking load and small ductility, their micro-structure similar to that of hardened carbon steels, their coercive force for magnetism, and, above all, their property of being softened by tempering below the point of transformation during heating. Plotting as a diagram the relations between the percentages of nickel and the breaking loads of the annealed specimens, the rapid increase between G (7·65 per cent. of nickel) and I (11·39 per cent. of nickel) showed the passage from alloys with little or no self-hardening properties to the self-hardening alloys. It was as if in a series of carbon steels one curve joined the soft specimens in their annealed condition with the hard specimens hardened in oil. The right-hand portion B′C′ of the curve A′B′C′ of the St. Etienne annealed steels was in reality the prolongation of the left-hand portion A′B″ of the curve of the same steels

Mr. Osmond.



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Mr. Osmond. water-quenched. The true curve of annealed alloys would be similar to A′R if alloys could be completely annealed; but only a rough approximation could be obtained by tempering the specimens as nearly as possible at the point of transformation during heating. From this discussion, it might be deduced that:—(1) Nickel might by itself make iron capable of being hardened by aid of rapid cooling (St. Etienne series A), if the percentage of nickel was not great enough to produce spontaneous hardening by slow cooling. Water-quenching then lowered the points of transformation of the iron into the region where these transformations remained incomplete. (2) In steels containing 15 per cent. of nickel, and a variable percentage of carbon, the carbon acted positively up to that temperature of transformation corresponding with the maximum self-hardening compatible with the percentage of nickel, and negatively as the point of non-transformation was approached. (3) In steels containing 25 per cent. of nickel, and a variable percentage of carbon, the carbon acted negatively from the origin of the series, since that origin was in the neighbourhood of non-transformation. Alloys of this series which contained 0·20 per cent. of carbon or more (St. Etienne series D) were not transformed. (4) The magnetic induction was feeble whatever the field in the alloys I, K, L, simply because these alloys, incompletely transformed, contained only a portion of their iron in a magnetizable condition, the remainder being allotropic. The above explanations possibly conflicted with many preconceptions; they might, however, appear simple at some future time. But if the writer was able to give expression to them, and to have clear ideas on the subject of nickel steel, he had been greatly aided in arriving at his opinions by the whole work of the Author, and had pleasure in rendering to this work the high recognition it deserved.

Mr. Segundo. Mr. E. C. DE SEGUNDO stated that he had lately obtained some interesting results from specimens of steel alloyed with nickel subjected to pure tensile stress. All the specimens, which had been kindly furnished by Mr. Hadfield, were nearly 0·71 inch in diameter, and extensions were measured over a clear length of 10 inches. Considerable difficulty was experienced in turning some of the specimens on account of their extreme hardness. Prof. Hudson Beare had kindly allowed the use of the testing-machine at University College for this purpose, and had placed at Mr. de Segundo's disposal a most accurate form of extensometer. The determination of the set point, to which particular attention was paid, might therefore be considered to have been arrived at

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without serious error. The chief results obtained having been already alluded to, it was perhaps only necessary to refer to a somewhat remarkable feature in the history of one of the specimens described by Mr. Hadfield as "nickel steel of very high tenacity and ductility, set point somewhat low." This specimen showed the first appreciable amount of set at a load of 6,800 lbs. A well-defined limit of elasticity was observed at 20,400 lbs. load, and the piece broke down at a load of 46,020 lbs. rising to 46,620 lbs. at fracture. Owing to its extreme ductility it was to be expected that the load at fracture would be less than the load at which the piece first broke down. This, however, was not the case. A careful manipulation of the weight on the steel-yard revealed a series of breakdown points, the actual load at fracture being 44,620 lbs. The total elongation was about 59 per cent. on the original length of 10 inches. There was no marked drawing down at fracture, the diameter being reduced almost uniformly throughout the length of 10 inches. The stress per square inch at fracture was therefore considerably greater than that at which the piece broke down first. This combination of extremely high tensile strength, unusually great ductility and practically uniform reduction of area is certainly remarkable. Some time ago Mr. de Segundo had occasion to test some of Mr. Hadfield's manganese steel and had found somewhat similar characteristics, though not so marked in extent. Mr. de Segundo.

Mr. R. A. Hadfield, in reply to the Correspondence, remarked that from Mr. Ashton's conclusions it would appear that carbon steel was not and nickel steel was liable to segregation. This was not correct, as the former had without doubt been proved to be liable to this trouble, whereas nickel steel, as far as the Author had been able to observe, was not affected in this manner. The Bethlehem Company, after not only a considerable number of experiments, but after many years of practical experience, had also come to this conclusion. It was very important to learn from Dr. Fleming's contribution that the electrical resistance of pure nickel was so much lower than hitherto accepted. The very valuable series of researches Mr. Osmond had carried out made the Author specially desirous to recognize to the full the value of Mr. Osmond's work, whether his criticism be for or against the opinions expressed in the Paper. As regards the differences mentioned, no one worker could expect to entirely avoid errors, but as regards Mr. Osmond's views on allotropy, he did not think that the facts mentioned bore the interpretation given. Whilst Mr. Osmond's remarks suggested valuable lines for further research, Mr. Hadfield

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Mr. Hadfield. he did not consider that the conclusions arrived at would be those referred to. Allotropists appeared to overlook the fact that the very general manner in which their views were often expressed is evidence that they were attempting to cover too much ground. For example, Mr. Osmond's arguments regarding the hardness noticed in this nickel-iron alloy might apply if the hardness of any of the specimens resembled in any way that of hardened carbon steel; but it was not so, there was not a single specimen which could not be machined. This being so, of what service, as regards the point in question, viz., the existence of an allotropic or hard Beta form of iron, was it to quote tests which had really no bearing upon the vital point as to whether the hardness noticed in hardened high carbon steel could be obtained from alloys other than those of iron and carbon? If Mr. Osmond and those who agreed with him would bring forward allotropy from another point of view, apart from its bearing upon dead hard carbon steel, the Author did not think great objection would be found by carbonists. Opponents might or might not be correct, but the views they put forward did not affect the point for which "carbonists" had fought so hard and so long, and which was, in the Author's opinion, confirmed by the results obtained from the alloys dealt with in the Paper. The Author admitted, as mentioned in the Paper, that it was difficult to explain the behaviour of some of the curious alloys described, but he thought that most of Mr. Osmond's interesting and able arguments were met by the results the Author had obtained from two of the nickel-iron alloys where a comparison was possible between two specimen alloys of similar contents as regards nickel, but varying in their carbon and manganese contents. The following Table showed these results:—

COMPRESSION RESULTS OF CAST ALLOYS OF IRON AND NICKEL.

| Specimen Mark. | Analysis. | | | Elastic Limit in Tons per Square Inch. | Total Compression by a Load of 100 Tons per Square Inch. |
|---|---|---|---|---|---|
| | C. | Mn. | Ni. | | |
| | Per cent. | Per cent. | Per cent. | | Per cent. |
| 1,287 I | 0·18 | 0·93 | 11·39 | 66 | 3·19 |
| 1,454 | 0·12 | 0·11 | 14·40 | 50 | 14·65 |

From the Table it would be seen that the specimen 1,454, containing lower carbon and manganese, shortened 14·65 per cent.

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against 3·19 per cent. in specimen 1,287 I. This comparison gave a remarkable proof of the influence of small quantities of other elements. It certainly showed that when the carbon percentage was reduced the material had very different properties; in other words, it was a fresh proof of the power of this element. Without, too, in any way questioning the St. Etienne results referred to by Mr. Osmond, it would be much more satisfactory if the full analyses of the alloys experimented upon had been given, as in the absence of these it was really very difficult to offer a definite reply. It was also hard to believe that a series of no less than ten specimens, each varying in their nickel contents, could possess such uniformity as to show, according to the figures given, only 0·02 per cent. difference in their carbon contents, and absolutely alike as regards their manganese contents, viz., 0·04 per cent. In addition, no details were given as to the elastic limit, elongation and reduction in area of the various specimens. As pointed out in the Paper, even the comparatively small percentages of carbon present in the specimens produced by the Author had decidedly great influence. If it had been possible to produce carbonless specimens, no doubt the material would have been softer. None of the specimens in the hardest zone (10 per cent. Ni to 16 per cent. Ni) could be termed really hard in the true sense of the word, or were comparable with hardened high carbon steel. This was fully dealt with in the Paper. Those who believed in allotropy appeared to overlook the fact that great increase in tenacity may be obtained without seriously affecting hardness, that was, as compared with the water-quenched hardness of high carbon steel. Until this result was obtained surely the carbon theory was quite sufficient, especially after the valuable research work that had been done in this direction by Abel, Muller, Ledebur, Arnold, and Osmond. The Author, in conclusion, thanked Mr. Osmond sincerely for his interesting contribution, and believed that the tendency of research work was now to bring carbonists and allotropists much nearer than had been the case for several years. Little by little from each side more light was being thrown on this important question, and he ventured to think that much of this was coming from workers in this special study of alloys of iron with various elements. The Institution early recognized the importance of this kind of research work in the generous aid given to the Author in the publication of his Paper in 1888 on "Alloys of Iron and Manganese," an account of probably the first systematic research in this direction.

Mr. Hadfield.

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11 April, 1899.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

*Members.*

Charles Hamlet Cooper.
Harley Hugh Dalrymple-Hay.
James Thomas Ford.
Charles George Henzell.
Sidney Richard Lowcock.
George Champion McDonald.
Arthur Woodroffe Manton.
Henry Thomas Simpson Ward.

And that the following Candidates had been admitted as

*Students.*

Arthur Goodwin Brown.
William Lyon Browne, Jun.
Herbert Mitchell Butterfield.
Stanley Haydon Bywaters.
Baltasar Fernandez Cué.
Roland Dudley.
Arthur Reginald Dyer.
John Lockhart Elder.
Edward Falk.
Charles Frederick Farrington.
Edmund Dean Foster, M.Sc. (*Victoria.*)
Aubrey George Forster Heather.
William Alban Hewett.
Francis William Hewitt, B.Sc. (*Victoria.*)
John Wykeham Hopkyns.
John Fredrick Jones.
Edmund David Kibble.
Cyril Landon.
Hugh Leader.
Frank Norman.
Fleetwood Keighly Peach.
Reginald Peel.
Gilbert Ashleigh Phear.
Edward Douglas Phillips.
Walter Patrick Frear Phillips.
Richard Reynell, Jun.
Ben Albert Rhodes.
Frank Sharman Rishworth, B.E. (*Royal.*)
Charle Guilliaume Rocher.
Ernest Hinkly Salmon.
William Charles Silliton.
William Simms.
Leonard Southerns.
Herbert Leslie Stevens.
John Sewell Walton.
Arthur Walburgh Ward.
Fred Wiley.
James Stanley Williams.
Andrew Williamson.
Cyril Frederick Willson.
Frederic George Wolstenholme.

The Candidates balloted for and duly elected were: as

*Member.*

John Thomas Nicolson, D.Sc. (*Edin.*).

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*Associate Members.*

Sydney Harry Abbott.
Frank William Arnold, Stud. Inst. C.E.
Walter Henry Bell.
John Campbell Boyd.
George Herbert Broome.
Charles Orr Campbell, Stud. Inst. C.E.
William Alexander Cheeke.
Owen Henry Clarke.
George Robert Cowdery.
Edgar Mark Eden, Stud. Inst. C.E.
John Garnar Flood, B.A. (*Cantab.*)
Frederic William Gaskin, Stud. Inst. C.E.
Thomas Sydney Fletcher Gibson.
Humphrey Harford Gostwyck Gostwyck.
Edward Long Grove.
John Willim Hall.
John Russell Hart, B.A. (*Cantab.*), Stud. Inst. C.E.
Charles Harold Hill.
Alaric Hope.
Walter Hudson.
James Thomas Jackson, M.A., B.A.I. (*Dubl.*)
George Baldwin Latham.
Francis Joseph Lobley.
Gerald Gascoigne Lynde.
Robert William Menmuir.
Herbert Elphinstone Montgomery.
Frank Morgan.
William Morrison, B.Sc. (*Glas.*)
John Thomas Newham.
John Joseph Nolan.
Eustace William Porter.
Reginald Arthur Ryves.
Charles William Scott, B.A.I. (*Dubl.*)
William Jones Steele.
John Charles Taylor, R.N.R.
Edgar William Timmis.
Laurence Maxwell Waterhouse.
Leonard Kingsley Watson.
Eric Hamilton Whiteford.
Oliver Winder, Stud. Inst. C.E.

The discussion upon the Paper "Alloys of Iron and Nickel," was continued and concluded.

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18 April, 1899.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

(*Paper No. 3155.*)

# "Buenos Ayres Harbour Works."

By JAMES MURRAY DOBSON, M. Inst. C.E.

As early as 1862 the late Mr. Eduardo Madero, of Buenos Ayres, turned his attention to the question of docks for the port of that city; and in 1865 he applied to Congress for permission to construct them at his own cost, but the application was rejected. Four years later he presented another application similar to the first, which suffered the same fate; and it was not until after twenty years of incessant labour, or in the year 1882, when he made his third application to Congress to build them at the cost of the nation, that he succeeded in obtaining an Act, under which the Executive Government were authorized to contract with him for the construction of docks and warehouses for the import and export of merchandise, together with the entrance channels. The docks were to be constructed on the riverside of Buenos Ayres between the gasworks on the north and the Riachuelo River on the south.

In the Act it was provided that the works should be directed by some hydraulic engineer of acknowledged reputation and experience, and for this purpose Mr. Madero, in 1883, upon the recommendation of Messrs. Baring Brothers, applied to the late Sir John Hawkshaw, Past-President Inst. C.E., to undertake the engineering. On the 28th March, 1884, the firm of Sir John Hawkshaw, Son and Hayter made a report to Mr. Madero upon the whole question. In that report it was stated that, after considering the various schemes proposed during the last twenty-four years, the firm also selected the foreshore in front of the town as the best situation for the docks, thereby providing for the trade of the port with the least disturbance of existing conditions.

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Subsequently this report was approved and the appointment of Sir John Hawkshaw, Son and Hayter was confirmed, the term of one year being fixed for the preparation of the detailed plans, specification and estimates. On the strong recommendation of Sir John Hawkshaw a contract for the general works was entered into between Mr. Eduardo Madero and the late Mr. Thomas Andrew Walker, a similar engagement being also made with Messrs. Sir W. G. Armstrong, Mitchell and Co. for the whole of the hydraulic machinery.

In August 1885 the Author, with a staff of engineers, sailed from England to prepare the surveys, detailed plans and estimates. Shortly afterwards Mr. Walker sent out two of his staff with the view to obtain the necessary information to enable him to make up his estimates for the work, and to verify the particulars with which he had already been furnished. In October of the same year Mr. Hawkshaw and Mr. T. A. Walker joined the staffs at Buenos Ayres, and remained there for some months until the plans and specification were completed.

In the preparation of the plans two points required to be very carefully studied:—(1) The exact position of the docks; and (2) the direction of the entrance channel.

(1) With reference to the position of the docks, many plans had been submitted to Government, and in some of these the site was fixed in front of the town; none however provided for sluicing the docks, which was most important and necessary, bearing in mind the health of the city. The Hon. R. C. Parsons, in a Paper on the sanitary works of Buenos Ayres,[1] remarks: "As the construction of the harbour has passed into other hands, it is only necessary to state that the works have been carried out in the same position as that advocated by Mr. Bateman, the only essential difference between his design and that adopted being the introduction of lock-gates, with the object of maintaining the water in the docks at a nearly constant level." It is true that the docks, as constructed, are in front of the city, as in Mr. Bateman's plan, but there are many other great and important differences between the two schemes besides the introduction of lock-gates, which in itself is of such vital importance, while the two principal reasons that led to the lock-gates being introduced have been overlooked. In the first place the gates were provided not so much "with the object of maintaining the water in the docks at a nearly constant level" as for the purpose of preventing it from falling

[1] Minutes of Proceedings Inst. C.E., vol. cxxiv. p. 2.

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below the level of zero or low water, thereby enabling vessels always to remain afloat in the docks, and at the same time to allow all ships of light draught to leave them if necessary, when the level of the river was below zero. In the second place the southernmost pair of gates, which point outwards, are constructed with the object of preventing the water of the Riachuelo, when in a turbid state, from entering the docks, and also to enable the docks to be more thoroughly sluiced if required. By closing these gates at low water the rising tide would be compelled to enter at the north end, and then by closing the north lock-gates at high water the falling tide would have to run out through the south lock, thus entirely changing the water in the docks and preventing the possibility of its becoming stagnant and consequently dangerous to the health of the city.

Since the works have been completed and the north basin opened, it has been found, from experiments made with floats, that the current in the docks is better even than was anticipated, and that with a good average tide and a strong north or south wind, there is as much as 850 feet per hour, so that the closing of the gates in order to sluice will be only occasionally needed.

In the River Plate not only does the water sometimes rise to an exceptionally high level, commonly known as the "Santa Rosa," but it sometimes also falls very low, as upon the 11th May, 1889, when the water was 6 feet 6 inches below zero, on the 2nd May, 1890, when it was 8 feet 2 inches below zero, and upon the 18th August, 1893, when 5 feet 3 inches below zero; and if the walls of the docks had been taken down deep enough so that vessels drawing 23 feet could be kept afloat, the cost would have been greater than the cost of the locks without gaining the advantages sought to be obtained. For instance, if the walls had been deepened 8 feet the cost would have been :—

| | $ Gold. |
|---|---|
| Excavation, 1,099,699 cubic metres at $0·63 . . . = | 692,810 |
| Masonry 100,209 cubic metres at $20·286 . . . = | 2,032,839 |
| | 2,725,649 |
| While the extra cost of the two locks, instead of two passages, has been . . . . . | 1,320,169 |
| Difference in favour of locks . . . | $1,405,480 |

Consequently, after carefully weighing all these matters, it was decided to place the docks parallel to the coast and provide locks at both ends. In Mr. Bateman's proposal for a port he had intended to empty the storm-water drains into the proposed harbour

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or basin, and since the construction of the docks the question of allowing the storm-waters to run into the docks has been repeatedly suggested; but it has always been most strongly opposed by the engineers, on the ground of danger to the health of the city. The late Mr. Harrison Hayter specially dealt with this subject when he visited the works in 1888. It is needless to state that storm-waters like those at Buenos Ayres bring down with them a very large amount of objectionable matter.

(2) With regard to the direction of the entrance or northern channel, at first this was laid out on the plans to run in a north-easterly direction from the north basin to what is known as the outer roads, where there is a long stretch of water having an average depth of 20 feet 3 inches below zero or low water. It was then proposed to extend it in a south-easterly direction to the bar anchorage. After carefully studying the river and finding that the direction suggested for the first portion would practically run directly across the stream, as in the case of the south channel, thereby in the opinion of the engineers increasing the silting, it was decided to turn the channel as quickly as practicable into the run of the river. The lines of these two channels are shown in Figs. 10, Plate 4.

The plans, specification, and estimates were completed and signed on the 12th December, 1885, and the plans were then submitted to General Roca by Mr. Hawkshaw, who, with the Author, returned to England in January 1886. In May of the following year the Author was asked to go to Buenos Ayres and act as representative and chief engineer for the firm of Sir John Hawkshaw, Son, and Hayter, which subsequently became Hawkshaw, Hayter and Dobson, this latter alteration being approved by the Argentine Government.

As the works had to be commenced, in order to comply with the conditions of the contract, on or before the 1st April, 1887, and it was impossible to get the staffs of the engineers and contractor together in time, Mr. Walker sent out Mr. Edward M. Simpson in advance to Buenos Ayres to cut the first sod, which was done on the 1st April, 1887. Fig. 1, Plate 4, shows the line of the foreshore when the surveys were made in 1885, while Fig. 2 shows the docks, basins, locks, &c., as completed in 1898.

## Description of Works.

The works in the original contract were divided into nine sections; each of the dock sections was to be complete in itself,

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together with railways and hydraulic machinery, but the number of warehouses and sheds was left for settlement as the works proceeded. The whole of the works were to be finished in six and a half years.

In July, 1887, a good start had been made, and the Executive Government decided to have a grand inauguration in which all the contractor's plant was to play an important part. This inauguration was fixed by the Government for Sunday, 17th July, and, although the Author pointed out that it had been specially agreed that no unnecessary work should be carried out on Sundays, still the Executive did not at first fall in with this idea, but a "Santa Rosa," accompanied by a heavy storm, did what the engineers had no power to prevent, as it washed away the whole of the embankment, thus leaving no lines for the locomotives and wagons to run over. From that day no request has ever been made to have any kind of ceremony in connection with these works on a Sunday, and the Author takes this opportunity of thanking the Executive Government for their consideration in this as in many other matters.

*South Basin.*—The basin, which has a water-area of 35 acres, was in the contract only 600 lineal metres (656 yards) in length, it being the intention of the Executive that the additional length of wharfing required to connect it with the Riachuelo Wharfing should be built by the Riachuelo Commission. As it was apparent that the Buenos Ayres Harbour Works portion would be completed first and could not be used until the other portion was finished, it was suggested that this also should be included in the harbour works contract, to which the Government assented; so that, on the west side of the basin, there is now a wharfing 1,038 metres (1,135 yards) in length, of pitch pine with elm fenders and a hardwood curb, while on the east side a bank was formed and covered with granite pitching 18 inches thick laid on 12 inches of small broken stone. Sections of the timber wharfing and pitched slope, varied so as to suit the different conditions of the ground, are shown in Figs. 3, Plate 4.

The bank on the east side of the basin gave considerable trouble on account of a layer of fine sand in the existing ground underneath; however, pockets were made in the bank 2 metres (6 feet 6 inches) wide, at distances varying between 7 metres and 30 metres apart, which were filled with rubble stone, and no further difficulty was experienced.

The depth of water in the South Basin is 21 feet 3 inches below zero, or L.W. ordinary spring tides, which is 62 feet 4 inches

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below the marble star in the portico of the south front of the Cathedral. This zero, which is the same as that fixed by Lieutenant Sidney when surveying the River Plate, is, from the records of the automatic tide-gauge (see Appendix I), some 11·6 inches lower than what would correspond to the average L.W., and this consequently is an advantage to the ships navigating the River Plate.

On the 28th January, 1889, the South Basin was officially opened by Dr. Carlos Pellegrini, on behalf of the President, the Argentine ironclad "Almirante Brown" having been brought up the south channel into the new basin as well as the M.M.S.S. "Orenoque." In his opening speech Dr. Pellegrini referred to the fact, that this was the first time a contract in the Argentine Republic had been completed to date, and in the name of the nation thanked the concessionnaires, engineers and contractor accordingly.

The trade of the city of Buenos Ayres up to this period had nearly all been carried on between the shore and the steamers by lighters and small steam tenders. The usual anchorage for the ocean steamers was in the "Bar Anchorage," a distance of about 14 miles from the city. The cargoes were transhipped into lighters, which brought them as near to the shore as possible, and from this point they were taken to the Custom House in specially constructed carts with very large wheels. Passengers were transhipped in the bar anchorage into small steam tenders and were brought to a point about 500 metres from the end of the passenger mole. From these tenders, when there was sufficient water, they were taken ashore in small boats, while if the water was too low to go alongside the mole—as in the case when the Author was once landed—they also had to be brought ashore in carts. Since the completion of the South Basin, however, all this has been changed, passengers being able to embark or disembark in perfect comfort, while all the cargoes are now landed on the quays.

*South Lock.*—The South Basin is connected with Dock No. 1 by a lock shown in Fig. 2. Originally it was intended to make this lock 80 metres (262 feet 6 inches) long between the sills, but before the South Basin was completed the Government decided to make it 135 metres (443 feet). The lock is provided with three pairs of gates, the south pair, as already stated, pointing outwards. The width of the lock is 20 metres (65 feet 7 inches) at coping level, with a depth over the sills of 21 feet 9 inches below zero. The gates, which are shown in Figs. 6, are built of greenheart; the two inner pairs are designed to hold up the water to a level of 8 feet above zero or 16 feet 2 inches above the lowest tide. The

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weight of one of the inner pairs of gates is 206 tons. The lock is crossed by a swing-bridge, having a double line for railway as well as for tram traffic. Both the gates and bridge are worked by hydraulic power. The lock is connected with a series of docks, four in number, entering No. 1 dock at its south-east corner.

*Docks.*—Nos. 1 and 2 have each a water area of 23 acres, each being 570 metres (623 yards) long by 160 metres (175 yards) wide, with a quay length of 1,420 metres (1,553 yards). No. 3 has a water area of 27 acres, is 690 metres (755 yards) long by 160 metres (175 yards) wide, with a quay length of 1,660 metres (1,815 yards). No. 4 has a water area of 25 acres, is 630 metres (689 yards) long by 160 metres (175 yards) wide, with a quay length of 1,535 metres (1,679 yards).

All four docks have a depth of 23 feet 9 inches below L.W. or zero, so that however low may be the river there should never be less than 23 feet 9 inches in the docks. The docks are united by passages 20 metres (65 feet 7 inches) in width, each passage being crossed by a swing-bridge of the same length as that over the South Lock. Dock No. 4 is entered at its northern end by the North Lock. This lock opens out into the North Basin, which has a water area of 41 acres, a quay length of 1,409 metres (1,541 yards) and a depth of 21 feet 3 inches below L.W. On the east side of the North Basin is the northern entrance 100 metres (328 feet) wide, leading to the north channel, while on the north side are the entrances to the two graving docks to which reference will be made later. The total water area of the two basins and four docks is 174 acres, and the total length of quays equal 8,482 lineal metres (9,276 yards).

During the construction of the works the newspapers continually tried to prove that when the docks were finished they would be practically cesspools, and at one time so influenced the Government that they ordered an outlet or sluice to be put in at the north east corner of dock No. 3, to satisfy the public who were scared by the fear of fever; everything was done on the part of the engineers and concessionnaires to try and prevent this needless expenditure—there being no truth whatever in any of these statements—nevertheless the sluice was built, including the hydraulic machinery, at a cost of £13,118, but was never once used for the purpose intended. The docks, passages, and lock walls are all built of rubble masonry of granite, the coping, ...ones, quoins, steps, and machinery foundations, are of ashlar

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masonry of granite. In order to give an idea of the great amount of work that has been carried out, it is sufficient to state that in dock No. 1, in the month of July, 1889, 13,361 cubic metres (17,476 cubic yards) of rubble masonry were built. This required some 26,700 tons of stone to be brought from the contractor's quarries at Conchillas, and the Author believes that this is the largest amount of masonry ever built on one work or section of work in one month.

The works were not completed quite in the order originally intended owing to the Government having to stop the same for two months, and to make arrangements to slacken down, but the following Table gives the various dates when the docks, locks, and basins, &c., were officially opened:—

| | |
|---|---|
| South Basin . . . . . | Opened 28 January, 1889. |
| South Lock, Dock No. 1, hydraulic-engine house and engines . . . | „ 31 January, 1890. |
| Dock No. 2 . . . . . | „ 26 September, 1890. |
| Dock No. 3 . . . . . | „ 31 March, 1892. |
| Dock No. 4, North Lock, North Basin and Graving Docks . . . . . | „ 7 March, 1897. |
| The first half of the North Channel . | „ 15 June, 1897. |
| The second half of the North Channel, with all the buoys and beacons . . | „ 31 March, 1898. |

*North Lock.*—This lock is 25 metres (82 feet) wide at the coping, has a length between the sills of 155 metres (508 feet 6 inches), with a depth at low water of 22 feet on the sills. It is crossed by a swing-bridge of the same type as the others. In the construction of this lock, Figs. 4, a very large bed of running sand was met with just at the intended level of the bottom of the foundation of the north sill. The sand was so troublesome that all pumping had to be at once suspended, and the level of the bottom of the foundations raised and widened out so as to reduce the weight per square metre on the soft white tosca overlying the running sand. To carry out this work the Author ordered an iron cylinder 8 feet in diameter to be sunk through the white tosca and running sand, and into the hard tosca, all the excavation being performed by a diver. When the cylinder was well down into the hard tosca a good layer of strong concrete was put in, making the cylinder quite watertight below, and in the white tosca about 1 foot below the level of the foundations, but 2 feet above the level of the running sand, large holes were cut in the cylinder to allow the water to run into it. A centrifugal pump was fixed in the cylinder, which, working continuously, kept the water below the level of the foundations. Before building the masonry of the



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north sill, the entire surface was covered with a layer of concrete 25 inches thick. Placing this concrete in bags was at first tried, but did not answer, the ground being so soft; it was then proposed that canvas should be laid down in long strips with the joints so placed that the water would run underneath. This plan answered well, and although the level at which the canvas was laid was only 2 feet above the running sand, the whole of the concrete was put in quite dry. When the invert was completed the cylinder was filled with concrete and built over, the water from the holes being drained into one vertical pipe which was carried up to the top of the invert, and cut off at that level. The gates for this lock, Figs. 6, being of a greater width than those in the south lock, are of a different construction. The weight of one pair of these gates is 301 tons.

After building the south lock it was found that the water, gas, telegraph, and telephone companies required to cross the docks with their pipes and wires, and as this could not be done in the south lock, where the hydraulic pipes were carried down the walls in a groove, and laid against a granite sill at the bottom of the lock, it was proposed, in the case of the north lock, to build a subway underneath, through which all the pipes and wires could be carried, and in the event of leakage, &c., be easily repaired. The subway, which is 2·3 metres (7 feet 6 inches) wide by 3 metres (9 feet 10 inches) high, is built in rubble masonry and lined with brickwork. Iron brackets are fixed in the wall to carry the pipes, and a small trolley line is laid along the bottom. A hydraulic ejector is placed in the shaft on the east wall, to empty the water that may run down from the top through the shafts, as there is little or no leakage in the subway itself.

### Sheds and Warehouses.

In the South Basin there are three sheds. In dock No. 1 there are two warehouses and three sheds. In dock No. 2 there are two warehouses and two sheds. In dock No. 3 there are five warehouses, and in dock No. 4 there are four warehouses. The total capacity of these sheds and warehouses, after deducting for passages as seen from Appendix II, amounts to 525,510 cubic metres (687,378 cubic yards) and the total floor area to 192,800 square metres (230,595 square yards).

*Sheds.*—The sheds, Figs. 4, Plate 4, were proposed originally to be of wood, but they were afterwards altered to iron, with corrugated iron roofs. With the exception of shed No. 8, at the south end of

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dock No. 1, they are all built on piles, it being anticipated that the ground made up from the excavation would settle considerably. Each shed has a platform 9·50 metres (31 feet) wide on the dock side, covered with a verandah. Shed No. 8 has a bond, and instead of being built on piles has brick walls. This shed is capable of receiving 7,700 barrels of wine in the bond.

*Warehouses.*—The first four warehouses in docks 1 and 2 have wooden roofs. So much difficulty was found in bringing the goods with the cranes to the doorways of the warehouses that a new design was prepared for the nine remaining warehouses in docks 3 and 4 as shown in Fig. 8. These warehouses have an extra floor, and have longitudinal platforms running the whole length of the front of the warehouses, so that goods can be deposited on any part of the platforms, and can then be taken into the warehouses afterwards. These warehouses are built with iron roofs, have iron partition doors and iron window frames. In the first warehouses built the roofs were covered with tiles laid on 1-inch planking, but in the last nine warehouses the roofs are of zinc laid on 1-inch planking.

The warehouses have hydraulic wall cranes fixed on the west side, four to each warehouse. These cranes will lift 30 cwt. from the bottom of the bonds to the top floor. In the nine new warehouses lifts are also provided to take the goods from the bonds to the top floor; there are four to each warehouse, each being capable of taking 30 cwt. up or down. In the lifts special safety cams are provided, which are brought into action by four strong spiral springs if anything goes wrong with the chain and wire rope; and in testing one of these lifts without any weight in it, the lifting chain and rope being disconnected and the cage tied to a cross timber with strong ropes, when these were severed with a blow of the hatchet, the cage only fell ½ inch. When tested with the 30-cwt. load in precisely the same way, the cage being fastened to a cross rail, the cage fell 6⅜ inches. The warehouses are built of rubble masonry up to the level of the quays, and from that level to the top, of brickwork. All the floors are of timber, with the exception of the ground floors over the bonds, which are of concrete in the proportion of 1 cement, 4 sand, and 6 stone, with a rendering of 1 inch of 1 cement and 1 of sand.



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### Temporary Banks.

In order to carry out these works, banks or dams had to be formed to enclose the different sections as shown in Fig. 1, Plate 4. At the south end of the South Basin, after one or two attempts had been made to form the bank by end tips, which were unsuccessful owing to the depth of water and the tide, crib-work was constructed so that side tips could be used, thus depositing the material more rapidly to form the bank. As each dock was completed a timber dam was erected in front of the passage which connected the completed dock with the one to be constructed. Between the South Basin and South Lock the contractor built a dam of rubble stone, but this was so costly to remove that it was not tried a second time; indeed, the stone dam practically required a wooden one to be constructed, in order to remove it.

### Outer or Exterior Wall.

In the original plans this wall was shown of timber, as there was not sufficient money available to build it of stone, but after the first two sections were finished, it was so clear that timber-work would not be maintained, and that if not maintained thoroughly its life would be very short, that the Government were strongly advised to alter the construction and substitute stone instead of wood, to which, after much consideration, they agreed. Sections of the wooden portions and also a section of the stone portion are shown in Figs. 9.

| | Lineal Metres. |
|---|---|
| Section No. 1, similar to section No. 2, but without fenders and sheet piling | 507 |
| Section No. 2 | 1,225 |
| „ „ 3 (portion) | 40 |
| „ „ 6 | 350 |
| Total length of timber-work | 2,122 |
| Stone section, which took the place of a portion of the timber section No. 3, of sections Nos. 4 and 5 | 2,376 |
| Total length of river-wharfing | 4,498 |

say 4,920 yards.

The pile-engines used for the work were the first ever constructed of their kind. They were virtually steam-hammers, but instead of the hammer-head moving and the cylinders remaining stationary, the hammer-head was fixed and the cylinder struck

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the blow. Each pile-engine was capable of driving two piles simultaneously. Steam was supplied from a boiler of the locomotive type to the cylinders through flexible pipes, so arranged that as the piles sank under the blows the steam-pipes followed without fracture. The greatest number of piles driven in one day by one double machine was twenty. The machines were constructed by Messrs. Whittaker, of Leeds, and did good work.

In the stone section a double row of close piling 3 metres (9 feet 10 inches) apart was first driven down into the tosca, braced at the top so as to allow the locomotives and wagons to run over them, the piles being cut off at a level of 22 metres (72 feet) above datum. A waling was put on the outside of each row of close piling and iron bolts $1\frac{3}{4}$ inch diameter and 1 metre (3 feet $3\frac{3}{8}$ inches) apart were inserted, coupling the two rows of piles together. The material was excavated by grabs and also by bag and spoon, and the concrete was brought up to the level of 19·79 above datum. Upon this concrete the rubble masonry wall was built, the piles being cut off afterwards at the level of the concrete.

## North Channel.

This channel, which extends from the North Basin to a point where it intersects the south or Riachuelo Channel, is 100 metres (328 feet) wide at the bottom, having slopes 1 in 10 with a depth of 21 feet below low water. From the entrance of the North Basin to K° 2·300 the dredging was in tosca, with a layer of between 1 foot 6 inches and 3 feet of sand on the top. From K° 2·300 to K° 4 it was in mud intermixed with sand, and from K° 4 to the end the dredging was in mud. The mud and sand were brought and pumped ashore, and thus the areas, Fig. 2, Plate 4, have all been made up to about 2 feet above quay level. The total area thus filled represents 1,190,000 square metres, or 294 acres.

The tosca which was dredged, amounting to 651,700 cubic metres, could not be pumped ashore, and in consequence great difficulty was experienced in landing it.

Almost at the beginning of the works the Author suggested to the contractor, that the best plan would be to fit barges with iron boxes, each holding enough to fill one wagon, but at that time it was considered too costly; however, after grab cranes had been tried and it was clearly shown that they would not discharge a barge in time, a plan was worked out by the contractor's

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engineer, Mr. George Rankin, which answered admirably. Barges were fitted with wooden boxes, having flap doors at the bottom with chains fixed to them, by which the box could be lifted out of the barges and placed in a dumping frame or cradle under which the wagons passed, when the box was put into the cradle and the chains let down, the weight of the material opening the two doors, the tosca dropped into the wagon. The box was then lifted out of the cradle and returned to the barge.

The bottom of the barge was open, but iron bars were inserted so that two came under each pair of doors, and when the boxes were replaced the doors coming into contact with the bars were kept shut. One of the barges, holding 136 cubic metres, could be discharged in 90 minutes, and nearly the whole of the tosca was landed in this way. When grab cranes were tried it was found that it took one crane eight hours to empty one of the barges containing 160 cubic metres. In the contract the Government have to pay for the material in the barges, making a reduction for increased bulk; in other words, they have to pay for what the material in the barges would measure in excavation at the bottom of the river. This question was very difficult to arrange, and a great many tests were made to try and arrive at a correct result. The Government engineer of the Riachuelo Works went into elaborate calculations on behalf of the Department of Engineers; but as these calculations were based upon the resistance of the material in the barges as compared with that of the river-bed, without taking into account the fact that the material had all been disturbed and undergone an entire change by dredging, the results arrived at were naturally rejected. In one experiment, an iron box, holding a little over 1 cubic metre, was nearly filled with mud from the barges, measured most accurately and the lid shut down and locked, the key being taken by the Government officials. Upon being opened in the presence of the same officials a fortnight later, the material was found to have increased instead of decreased in bulk, and this did not commend itself. At last the Government engineers agreed to carry out the test which the engineers considered was the only one likely to solve the difficulty, as to the increase of bulk for the sand, tosca, and mud.

### Dredging Tests.

*Sand.*—Immediately above the level of the tosca in dock No. 4 a block of sand was cut measuring exactly 1 metre by 1 metre by

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1 metre. This sand formed part of the original undisturbed river-bed. It was found more or less 1 metre under the river bottom, and may thus be taken as a fair sample of the sand being dredged, or at least as nearly so as possible. A wooden box 1 metre by 1 metre by 1·5 metre high was filled with water to a height of 0·50 metre, and after this the block of sand was thrown into it.

The distance from the surface of the sand to the top of the box was then measured, so as to arrive at an accurate average, and for this purpose the measurements were taken in regular sections with the following result:—

| Section 1. | Section 2. | Section 3. | Section 4. | Section 5. | Total. |
|---|---|---|---|---|---|
| Metres. | Metres. | Metres. | Metres. | Metres. | Metres. |
| 0·428 | 0·451 | 0·437 | 0·451 | 0·445 | 2·147 |
| 0·428 | 0·432 | 0·438 | 0·439 | 0·445 | 2·163 |
| 0·428 | 0·419 | 0·441 | 0·416 | 0·450 | 2·211 |
| 0·432 | 0·422 | 0·456 | 0·435 | 0·439 | 2·181 |
| 0·431 | 0·439 | 0·439 | 0·440 | 0·473 | 2·252 |
| 2·147 | 2·163 | 2·211 | 2·181 | 2·252 | 10·954 |

and $$\frac{10{\cdot}954}{25} \times 1 \times 1 = 0{\cdot}43816,$$

$$\therefore 1{\cdot}500 - 0{\cdot}43816 = 1{\cdot}06184 \text{ cubic metre.}$$

The cubic metre of sand *in sitú* had therefore become 1·06184 cubic metre in the box, showing an increase of volume of 6·184 per cent., or a deduction of 5·83 per cent. from the cube measured in the barges. The distance from the surface of the water to the top of the box averaged 0·2945 metre. The volume of sand and water was 1·2055 cubic metre, of which 1·06184 cubic metre was sand, while the volume of water above the sand was 0·14366 cubic metre. Deducting that quantity from the 0·500 cubic metre in the box leaves 0·35634 cubic metre as the amount of water absorbed by the sand, or 33·56 per cent. of its volume.

*Tosca.*—A block of tosca of the very hardest quality exactly 1 metre by 1 metre by 1 metre was prepared near the place where the test had been made with the sand. The tosca block was broken into pieces and put into a box measuring 1 metre by 1 metre by 1·5 metre high, 0·5 cubic metre of water being in the box as in the former test.

The measurements to the surface of the tosca were taken after

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the block had been broken up and put into the box and gave the following results:—

| Section 1. | Section 2. | Section 3. | Section 4. | Section 5. | Totals. |
|---|---|---|---|---|---|
| Metres. | Metres. | Metres. | Metres. | Metres. | Metres. |
| 0·250 | 0·243 | 0·276 | 0·253 | 0·320 | 1·171 |
| 0·211 | 0·228 | 0·231 | 0·258 | 0·254 | 1·147 |
| 0·225 | 0·210 | 0·240 | 0·248 | 0·260 | 1·242 |
| 0·235 | 0·226 | 0·238 | 0·238 | 0·252 | 1·248 |
| 0·250 | 0·240 | 0·257 | 0·251 | 0·247 | 1·333 |
| 1·171 | 1·147 | 1·242 | 1·248 | 1·333 | 6·141 |

$$\text{and } \frac{6 \cdot 141}{25} = 0 \cdot 24564 \text{ metre.}$$

The average depth of the tosca was therefore equal to 1·500 metre, less 0·24564 metre or 1·25436 cubic metre, showing an increased volume of 25·436 per cent., which is equal to a reduction of 20·28 per cent. from the cube of tosca measured in the barges. After this the distance of the water to the top of the box was measured, and gave an average of 0·14225 metre. The volume of tosca and water was therefore:—

| | Cubic Metre. |
|---|---|
| 1·500 − 0·14225 . . . . . | = 1·35775 |
| The volume of tosca . . . . . | 1·25436 |
| Therefore the volume of water on the top of the tosca . | 0·10339 |

Consequently 0·500 cubic metre of water − 0·10339 cubic metre = 0·39661 cubic metre of water absorbed by the tosca, or about 31·62 per cent. of its volume.

*Mud.*—With the object of making a test in the mud under the same conditions as those of the sand and tosca, a site was selected on the east side of the south basin at the south end, where the mud was found to be as nearly as possible in the same state as that in the bottom of the river.

The plan adopted was to force a box without a bottom into the mud until arriving at the tosca, and then to excavate that mud from the box, lift it to a height, and let it fall down a shoot into another box containing a certain amount of water. Box No. 1, which was put into the mud, measured 1·002 metre by 1·002 metre by 2·7 metres, and was pressed down to a level more or less 3 centimetres above the tosca, but was not strong enough to allow

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of its being forced down further. A cubic metre of mud was excavated from the inside of box No. 1, having first carefully measured the level of the same. It was carried up in buckets to a height not quite equal to the height of the dredger tumbler and was then thrown down a shoot into box No. 2, which was 1·002 metre by 1·002 metre by 2·7 metres and contained 0·25 metre of water.

The result of this test was an increase of 33·45 per cent., equal to a deduction of 25·07 per cent., but from measurements taken on the following day it was found that the surface of the mud in box No. 1 was higher than it was the day before, this disturbance evidently arising from a spring which had given much trouble when excavating the mud from the inside of box No. 1, and as this fact indicated the probability that a similar movement had taken place during the carrying out of the test another test was commenced, taking the mud as before from box No. 1; but the disturbance caused by the pressure of the water from the spring was such that it was impossible to continue the test, and it was decided to give it up. As there was therefore good reason to believe that the result of the first test made with mud could not be relied upon, on account of the spring, other measures were discussed in order to arrive at the deduction to be made; but in the end it was decided that the mode adopted was the correct one to follow, provided the conditions were satisfactory, and it was therefore arranged to make a further test similar to the first. Consequently an area of ground 7·2 metres by 9·3 metres was enclosed by planks well driven down into the tosca; all the material was then cleared away in this space from the surface of the ground to the level of the mud; a box, No. 1*a*, measuring 1 metre by 1 metre by 2·9825 metres was loaded until it penetrated through the mud and reached the tosca. The staging was heightened and the conditions made similar in every way to those of the dredger. The mud in the box No. 1*a*, after being carefully measured, was excavated and carried up the staging to the height of the dredger tumbler, when it was thrown down a shoot similar to that on the dredger and placed at the same inclination. The mud fell into box No. 2*a*, which was 1 metre by 1 metre by 1·5024 metre and containing 0·2500 metre of water. This test, which, as in the case of the sand and tosca tests, was most carefully carried out, showed an increase in volume of 13·24 per cent., equal to a deduction of 11·7 per cent. for the material in the barges. Another box, No. 3, 1 metre by 1 metre by 1·50325 metre, was also filled exactly in the same manner as box No. 2*a*, with mud from box No. 1*a*, and the measurements showed an increase of 11·65 per

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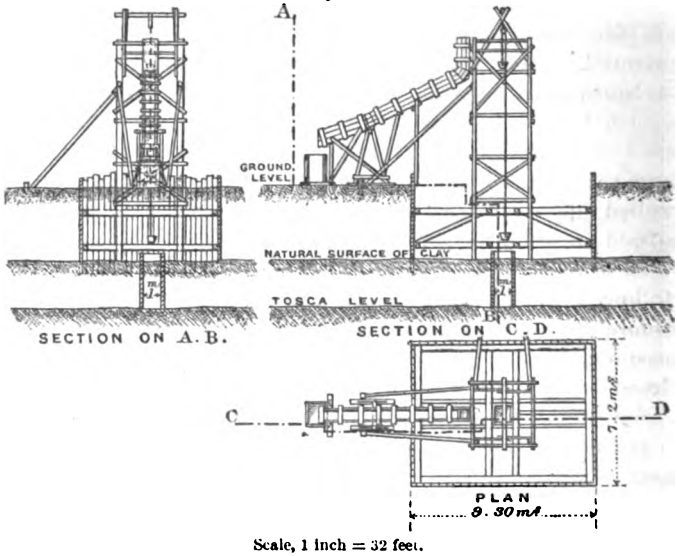
cent., equal to a deduction of 10·44 per cent. The average of these two last tests of mud gave 11·07 per cent. as the deduction to be made from the cube of mud measured in the barges. *Fig. 11* shows the arrangement of the staging, &c., for these last two tests.

The Government engineers were not satisfied with these tests, because in their opinion they did not give a sufficient deduction, and they proposed to make another test by taking sections very carefully over 30 square metres of the river-bed, dredging some 25 metres by 20 metres to a depth of 2 metres, and afterwards taking sections over the same ground in order to arrive at the increased volume of the material in the barges.

*Fig. 11.*




Scale, 1 inch = 32 feet.

STAGING FOR TESTING MUD.

The Author pointed out to the Department of Engineers that this was not a good test, as it would not give any deduction, but only shows that the quantity of mud in the barges was less than would fill the hole dredged. However, the Department of Engineers, although they understood this experiment had already been made, were incredulous, and decided that it should be carried out again. Sections were consequently taken over some 35 metres, and 25 metres by 20 metres dredged to a depth of 2 metres, after which sections were again taken over the same ground and the mud measured in the barges. From these soundings it was found that

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1261·08 cubic metres had been removed from the river-bed, while the measurement of the barges filled gave 964·31 cubic metres, that is to say, the actual excavation was 30·77 per cent. more than the quantity measured in the barges. This result, taken in conjunction with those of the previous tests, showed that in dredging the mud 32 per cent. of the material removed escaped from the dredger buckets and the barges, and was carried away by the stream, and therefore this test was really of no value, inasmuch as the question to be settled was, what would the material lifted and in the barges measure in excavation?

Owing to the suspension of the works and slackening down of the same, the dredging was greatly retarded and consequently very much increased in quantity. The total quantity of dredging carried out to the 31st March, 1898, including the maintenance of the first half of the channel from the date of its completion, was 7,346,818 cubic metres; of this quantity 651,700 cubic metres were tosca, 1,376,086 cubic metres were sand, and the remaining 5,319,032 cubic metres were mud intermixed with a little sand. The amount dredged between 1st June, 1897, and 31st March, 1898, was 2,583,891 cubic metres, or an average of 258,389 cubic metres per month, and of this quantity it must be borne in mind 1,413,310 cubic metres were pumped ashore, 876,853 cubic metres taken to sea, and 293,728 cubic metres of tosca were discharged by means of the wooden boxes. This involved working day and night, but the result showed that if 2,583,891 cubic metres could be dredged in 10 months, the whole channel, which according to the quantities taken from the contract drawing (with an allowance for silting) amounted to 4,500,000 cubic metres, could have been completed in less than 2 years, instead of the five which it took, owing in a large measure to the reasons given above.

In the north channel on the 31st March, 1898, there was no sounding throughout the whole 9·85 kilometres down the centre line of the northern half, which gave a less depth than 20 feet 11 inches, and this only occurred in one place for a distance of 20 metres; while down the centre line of the southern half there was no sounding that gave a less depth than 21 feet 3 inches below low water. The average of the whole of the soundings taken along the northern and southern centre lines gave a depth of 22 feet 8 inches below low water, while the cross sections, Figs. 10, are fair average sections of the channel on the 30th September, 1898. From the following Table will be seen the state of the north channel at the end of each month, together with the amount of silt dredged. This Table shows that the total dredging of silt amounted to

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486,847 cubic metres for 6 months, from the 31st March to 30th September, 1898, during the whole of which time the channel has always had a greater depth than 21 feet below low water, with the few exceptions referred to in the Table, while the average depth of the channel has been throughout its entire length 22 feet 3 inches below low water.

| Date. | Least Depth below Low Water in the Centre Line of the Northern Half. | Least Depth below Low Water in the Centre Line of the Southern Half. | Average of all the Soundings down the Centre Line of the Northern Half. Below Low Water. | Average of all the Soundings down the Centre Line of the Southern Half. Below Low Water. | Monthly Amount Dredged. |
|---|---|---|---|---|---|
| 1898. | Ft. Ins. | Ft. Ins. | Ft. Ins. | Ft. Ins. | Cub. Metres. |
| March 31 | 20 11 for about 20 metres | 21 3 | 22 8 | 22 8 | .. |
| April 30 | 21 0 | 20 6 for about 18 metres | 22 2 | 22 0 | 129,052 |
| May 31 | 20 11 for about 42 metres | 20 10 for about 20 metres | 22 9 | 22 9 | 73,763 |
| June 30 | 20 8 for about 60 metres | 20 11 for about 20 metres | 21 11 | 22 2 | 55,341 |
| July 31 | 21 1 | 21 3 | 22 3 | 22 4 | 82,411 |
| August 31 | 20 8 for about 50 metres | 21 0 | 22 0 | 22 2 | 92,511 |
| September 30 | 20 8 for about 200 metres | 20 10 for about 20 metres | 21 11 | 21 11 | 53,769 |
| .. | .. | .. | .. | Total | 486,847 |

In working out the probable quantity of silting, for a report of the engineers, which was sent to Government in 1897, it was found from careful observations taken in the first half of the channel at the outer end, that the silting would be between 800,000 cubic metres to 900,000 cubic metres per annum, and this is really verified by the 6 months' dredging, which gives 973,694 cubic metres per annum. *Fig. 12* shows the maintenance of the north channel from the 1st June, 1897, when the northern half was completed, until the completion of the whole channel on the 31st March, 1898. From this diagram will be seen the position of the maintenance dredgers each month, and therefore the portions of the channel where the greatest silting occurred, and consequently required the most dredging in maintenance. The diagram, *Fig. 13*, shows the maintenance of the whole of the channel for the six months

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from its completion on March 31st, 1898, until September 30th, 1898. From this diagram it will be seen that, excepting in April, only one dredger at a time has been engaged upon the maintenance, and that out of the 12·02 kilometres traversed, 7,300 lineal

*Fig. 12.*

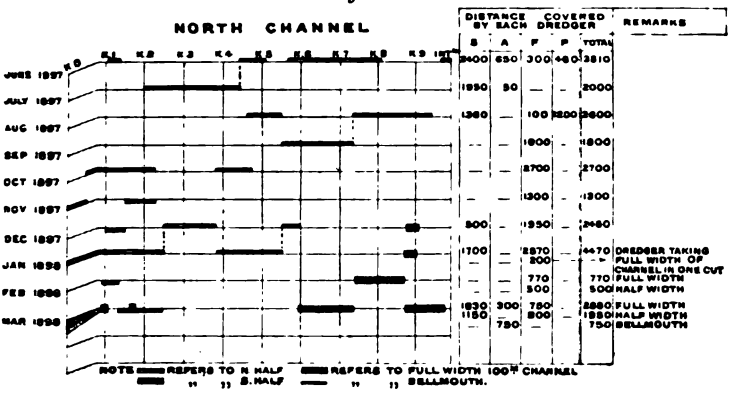
NORTH CHANNEL
DISTANCE COVERED BY EACH DREDGER
REMARKS
S A F P TOTAL
K0 K1 K2 K3 K4 K5 K6 K7 K8 K9 INT
JUNE 1897
JULY 1897
AUG 1897
SEP 1897
OCT 1897
NOV 1897
DEC 1897
JAN 1898
FEB 1898
MAR 1898
2400 650 300 460 3810
1950 50 — — 2000
1360 — 100 1200 2660
— — 1900 — 1900
— — 2700 — 2700
— — 1300 — 1300
500 — 1950 — 2460
1700 — 2870 — 4470 DREDGER TAKING FULL WIDTH OF CHANNEL IN ONE CUT
— — 200 — —
— — 770 — 770 FULL WIDTH
— — 500 — 500 HALF WIDTH
1830 300 780 — 2880 FULL WIDTH
1150 — 800 — 1950 HALF WIDTH
— 750 — — 750 BELLMOUTH
NOTE REFERS TO N HALF REFERS TO FULL WIDTH 100M CHANNEL
" " S. HALF " " BELLMOUTH.

DIAGRAM ILLUSTRATING THE MAINTENANCE OF THE NORTH CHANNEL FROM 1ST JUNE, 1897, TO 31ST MARCH, 1898.

metres have been between K 0 and K 4, where there is a large portion of sand and the natural surface of the river-bed is from 9 feet 8 inches at the north basin to 10 feet 2 inches at K 4 below low water. Very few of the channels or docks in the United

*Fig. 13.*

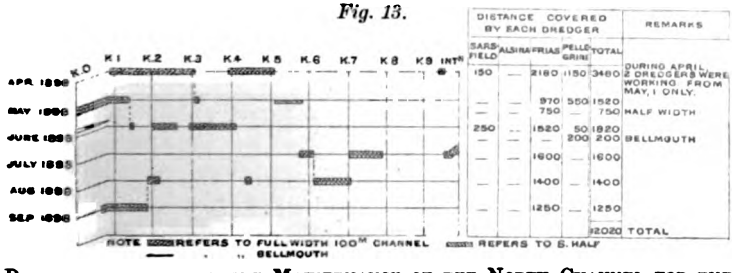
DISTANCE COVERED BY EACH DREDGER
REMARKS
SARSFIELD ALSINA FRIAS PELLEGRINI TOTAL
K0 K1 K2 K3 K4 K5 K6 K7 K8 K9 INT
APR. 1898
MAY 1898
JUNE 1898
JULY 1898
AUG 1898
SEP 1898
150 — 2180 1150 3480 DURING APRIL 2 DREDGERS WERE WORKING FROM MAY, 1 ONLY.
— — 970 550 1520
— — 750 — 750 HALF WIDTH
250 — 1520 50 1820
— — — 200 200 BELLMOUTH
— — 1600 — 1600
— — 1400 — 1400
— — 1250 — 1250
12020 TOTAL
NOTE REFERS TO FULL WIDTH 100M CHANNEL REFERS TO S. HALF
" BELLMOUTH

DIAGRAM ILLUSTRATING THE MAINTENANCE OF THE NORTH CHANNEL FOR THE 6 MONTHS MARCH–SEPTEMBER, 1898.

Kingdom can be maintained without dredging, and in Hull the dredging is considerably over 1,000,000 cubic yards per annum. It should be borne in mind that in the case of the north channel there is every probability that the amount of silting will decrease as the slopes find their natural inclinations.

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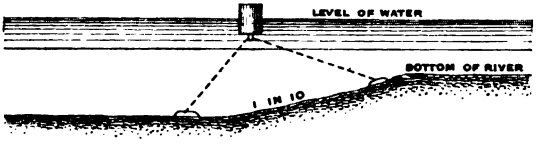
The north channel as stated was completed to the intersection with the south channel on the 31st March, 1898, and the decree was given receiving the same and handing it over for public service. Arrangements were however made and an "Acuerdo," signed by the President and Ministers, ordering Messrs. Madero & Sons to continue to maintain the said channel, and it is hoped that the Government will enter into a contract with that firm to undertake this maintenance for a term of years.

*Beacons and Buoys.*—The channel has six beacons erected in the length of 9·85 kilometres. The piles for the two beacons nearest the north entrance are driven into the tosca, but the piles for the other four beacons are in the mud, and in order to afford stable material into which to drive the piles, dredged tosca was deposited on the site of each of these four beacons, and after it had settled down in the mud, the iron piles were driven.

Buoys are moored every 1,000 metres apart with two chains to each buoy as shown in *Fig. 14*, so as to prevent them from being

*Fig. 14.*




carried out of the line with a strong northerly or southerly wind, and a large buoy 3·2 metres diameter by 4·572 metres high is anchored by four chains at the intersection of the two channels. It will be seen from Figs. 10, Plate 4, that the channel is not yet completed to deep water. From the intersection it was intended when the plans were prepared that the Government, who were dredging—by the Riachuelo Commission—the south channel, should have completed a channel from the intersection to deep water by the time the north channel was finished to that point, but such has not been the case, and every effort is now being made to induce the Government to arrange a contract to continue the north channel in a straight line to deep water.

*Tides.*—In connection with the dredging it was necessary to keep a complete record of the rise and fall of the river, for which purpose an automatic gauge, by Adie, was fixed, first in the South Basin, and afterwards at the river wall. This record was carefully tabulated for the years 1890 to 1894 inclusive, and the results are

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shown in Appendix I. From these Tables it will be seen that the level of the tides varies considerably, owing chiefly to the effect of the wind, but taking the average of all the tides, they are fairly constant, as the monthly variations closely follow the amount of discharge-water from the upper rivers; thus, while the mean level of the river in January was about 10·1 inches higher than in June, there was a corresponding difference of 1 foot 0·7 inch in mean high water. These tidal records also proved of great service in fixing the high-water line for the limit of private property along the foreshore, the uncertainty regarding which became apparent in connection with certain lands occupied by the works. To settle this question the Government appointed a Commission composed of Director-General Pirovano of the Department of Civil Engineers, Mr. Duclout, Director of the Riachuelo Works, Mr. Mansilla, the Maritime Prefect, and the Author as Directing Engineer of the Buenos Ayres Harbour Works, the latter being nominated to draw up a report for the guidance of the Commission. Owing to the frequent high tides caused by the wind, the nearest approach to high water ordinary spring tides which it was possible to arrive at by an approximation based on the average height of all the tides appeared too low, and as a compromise the Author recommended that the mean level of the tides which rose above the average height of all the tides should be taken. By this method he obtained the level of 5 feet above zero or 20·67 above datum, which was adopted by the Commission and afterwards approved by Government Decree dated the 31st May, 1895.

## Hydraulic Machinery.

The whole of the bridges, gates, sluices, capstans, cranes and lifts are worked by hydraulic power. In the hydraulic engine-house, which is erected at the south end of dock No. 1, there are two horizontal compound condensing-engines, each of 450 I.HP.; each engine has two high-pressure cylinders, 19¾ inches in diameter and 38 inches stroke, and two low-pressure cylinders, 37 inches diameter and 38 inches stroke. The high-pressure cylinders are fitted with double slides and variable-expansion gear. Each engine is provided with a condenser of the injection type, placed below the engine-house floor. An air-pump is fixed to each engine, which is worked from one of the crank-pins. A lift-pump for each engine is also worked from the opposite crank-pin to that which works the air-pump. There are four boilers of the Lanca-

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shire type, each 7 feet diameter and 27 feet long, having two flues crossed by three circulating tubes. A wrought-iron tank, 45 feet long by 15 feet wide and 3 feet deep, is erected over the boilers to receive the water raised by the lift-pump, for the supply of the force-pumps and also for supplying the boilers. An accumulator adjoins the engine-house, having a plunger of 20 inches diameter and 35 feet stroke, with wrought-iron weight-case and guide-bars, and fitted with an apparatus for regulating the working of the engines by the rise and fall of the plunger. Two similar accumulators with plungers of the same size, but having a stroke of 23 feet 6 inches, are erected, one on the east side between docks Nos. 1 and 2, and the other at the north-west corner of dock No. 4. Two pairs of fixed injector fire-hydrants are placed in the well adjoining the engine-house, from which the lift-pump and cold-water pump draw their supply, and which is connected with the dock by a culvert.

*Gate Machinery.*—The machinery for each leaf of each pair of gates consists of a pair of hydraulic cylinders with plungers, together with rollers and cast-iron frames for guiding the chains where they pass through the dock walls.

*Sluice Machines.*—Each machine consists of a copper-lined hydraulic cylinder, fixed vertically in the sluice-shaft. The sluice-doors are of greenheart timber.

*Capstans.*—The capstans are capable of hauling about 5 tons; they are fitted with hydraulic engines, having three oscillating cylinders, with spur and bevel gearing.

*Swing-Bridges.*—Each bridge is lifted from its bearings previously to being turned by a hydraulic press with plunger and capped resting-block, bolted to a steel box-girder riveted between the main girders. The bridge is turned by a pair of hydraulic cylinders with plungers and chains acting on a drum fixed to the underside of the bridge. The lifting- and turning-valves are arranged so that they are worked by a man standing beside the bridge. Cast-iron resting-plates are provided for carrying the weight of the bridge when across the dock entrance, and rollers are fixed near the tail end of the bridge, which run on a cast-iron roller-path, and presses acting on segments of the roller-path are arranged so as to raise the rollers to the level of the path when the bridge is to be swung. These presses are worked from the same valve as the central lifting press, provision being made for tilting the bridge from its bearings, in the event of the central press not being available, and for this purpose a pair of presses are fixed in the bridge-pit at the tail end with sliding resting-

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blocks, and by which means the tail end of the bridge can be lowered about 6 inches. The bridge has a counterweight of about 100 tons. The bridges are designed for a rolling load of 1½ ton per foot on each of the two lines of rails at the same time, and for 80 lbs. per square foot of footway, and the maximum weight on any one pair of wheels on the railway is taken at 16 tons.

*Cranes (Movable).*—The 30-cwt. cranes have either fixed rake or variable rake; they are capable of lifting a load of 30 cwt. through 50 feet, and having, in the case of the fixed rake, a radius of jib of 33 feet, while in the others the rake can be varied between 21 feet and 33 feet. The pedestals are mounted on four wheels set to a gauge of about 10 feet 3 inches, and supplied with screw chocks for relieving the weight of the cranes. Cast-iron counterbalance weights are fixed at the back of the pillars. The lifting machinery is within the pillar, and the turning machinery in the pedestal at the foot of the pillar. The valves are placed at the side of the pedestal, and so arranged that they can be worked by a man standing on a platform above them. The 5-ton cranes are of similar construction to the fixed rake cranes. There is one 30-ton crane which is capable of lifting that load through 50 feet. The pedestal is about 16 feet 9 inches high, fixed to the quay by holding-down bolts. All the machinery exposed to the accumulator pressure was tested to 2,500 lbs. per square inch before leaving the manufacturer's works, while the working pressure is 700 lbs. per square inch. There are 9½ miles of piping laid round the docks and in the warehouses.

## Graving Docks.

On the north side of the North Basin two graving docks, Figs. 15, Plate 4, have been constructed; the west one 150 metres long and the east one 180 metres measured from the sill to the coping at the head of the docks. The depth of water on the sills below low water is 6·104 metres, or 20 feet, and the width of the entrances 20 metres at coping level. Originally it was proposed by the Government to build two graving docks, one at the South Basin and the other at the North Basin; this was done because the North Basin was not completed and a graving dock was very much required. In preparing the original plans, the engineers, however, pointed out that it was not an economical arrangement to separate the docks, and provided for two being constructed at either end.



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Soon after this, the stopping and slackening down of the works took place, and when the graving dock question was again brought up the North Basin was completed, when it was at once decided, that both the docks should be constructed at that end, so as to avoid the extra expense of a second pumping station as well as additional shops. The walls of the two docks are built of rubble masonry of granite, with altars, copings, steps, &c., of ashlar masonry of granite.

In the west dock, which was the first commenced, the invert was built of bricks, but as it was impossible to procure sufficient bricks to complete the second invert—there being over 1,315,000 used in the invert of the west dock—concrete in the proportion of 4 of stone, 2 of sand and 1 cement, was substituted in the place of brickwork. In constructing these docks, a 9-inch earthenware pipe was laid down the centre in the tosca, to which branch pipes were connected, while the longitudinal pipe was continued straight up the back of the wall at the head of the dock and vertical connections were put in down the centre of the docks, holes being left right through the invert and carried up to the underside of the granite sets. After the pipes were laid and the water carried into a sump at the south end, a foot of strong concrete was placed all over the bottom, and upon this concrete the brick or concrete invert was built. On top of the inverts rubble masonry was carried up to a level of 0·15 metre or 6 inches below the floor, and upon this masonry a floor of "adoquines" (granite sets) was laid set in 3 to 1 mortar with a fall of 6 inches from the centre towards each side. After the work was all finished, temporary vertical pipes were fixed at the intermediate points, where the holes had been left in the inverts, and the whole of the work grouted with strong grout. Four cast-iron ladders and two slides with granite curbs are provided in each dock; also a rudder pit 6 metres long by 3·80 metres wide and 2·55 metres deep. The docks have an inclination on the floor of 1 in 300. The water is admitted to each dock by two sluices, one on either side of the dock, 1·372 metre by 1·83 metre, and with these two sluices it can be filled in about 20 minutes.

When the plans were being prepared, the Author strongly recommended the Government, that instead of wooden gates as first suggested in 1890, or ship caissons as recommended by the Department of Engineers, sliding caissons should be used to close the entrances, as although the first cost—owing to the recesses—necessary for the sliding caissons was heavy, still the facilities for repairs and (having the motive power at hand) the ease of manipu-

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lation would be very great, while the entrances could be closed in 5 minutes. Owing, however, to a difference of opinion between the War Office and the Department of Engineers, the War Office being in favour of the sliding caissons while the Department were in favour of the ship caissons, the result was that the work suffered, inasmuch as the Minister gave a decree ordering the entrances to be closed by ship caissons, and although ship caissons of the best type are provided, still it takes considerable time to put them in place while requiring many men to work them. Ever since the docks have been opened, there has been general regret that the sliding caissons were not adopted.

*Ship Caissons.*—These were constructed by Messrs. Sir W. G. Armstrong, Mitchell & Co., Limited. They are each 67 feet 3½ inches over all, 24 feet extreme breadth and 36 feet 5½ inches from coping to bottom of keel. Each is so designed that it will work at the low-water level, or 19·144 above datum, and that, with all machinery and ballast fixed, the top of the air-chamber is about level with the water outside, when the caisson is floating, which it commences to do when there is about 7 tons of water left in the adjusting tank. The working draft of the caisson is about 17 feet 7 inches, while the distance of its centre of gravity, with all ballast and machinery fixed, is not less than 1 foot below the centre of displacement. A water ballast tank is placed below the lower watertight deck, and by emptying this tank the draft of the caisson could be reduced if required from 17 feet 7 inches to 17 feet 3 inches. This can be done without endangering the stability of the caisson. The total weight of solid ballast required for each caisson is about 210 tons. The strength of the caisson is such that, whichever way it is placed in the groove, it will sustain the full pressure of the highest tide without the material being strained beyond one-fourth of its breaking strength. The roadway floor is of teak, the shutting keels and stems are of greenheart, and teak fenders on either side are secured between angles. A hydraulic ejector, which can be connected with the pressure main, is provided for raising the water from the lower adjusting tank into the upper adjusting tank and for emptying the lower ballast tank, and a separate hand-pump is also provided for the same purpose. The caissons were brought out in pieces, erected upon proper blocks partly across the entrances, and then slid into position. When the caisson has been brought into the groove, the lower tank flood-valves are opened, the upper tank drain valve being closed, and gradually the caisson sinks and comes to rest upon the bottom of the caisson



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groove; the flood-valves are then shut, but the tidal valves on the side of the north basin are left open, so that the water may have free access to the tidal chamber to rise and fall with the tide. At any convenient time after the caisson is sunk into position, the water in the lower tank is raised to the upper adjusting tank, either by means of the hydraulic ejector or the hand-pump. When the water from the lower tank has been pumped into the upper tank, and the water-level is the same in the North Basin as in the graving dock, the caisson is ready to rise, which is effected by opening the upper tank drain valve. As the water runs out of this tank the caisson gradually begins to float, and, freeing itself from water as it rises, finally clears itself from the grooves, when it can be drawn out of the dock entrance. At times of very high water-level, when the water on the dock sill exceeds 30 feet in depth, the lower tank flood-valves and the tidal chamber valves are all kept open, so as to prevent the caisson from being lifted out of position.

*Engine-House and Pumping Machinery.*—The pumping machinery, which was supplied by Messrs. Easton, Anderson and Goolden, Limited, was specified to empty one dock, containing 35,000 tons of water, in 3½ hours (due allowance being made for leakage); the mean lift was 13 feet 9 inches, ranging from zero to a maximum of 28 feet 9 inches; in other words, from high-water mark to the bottom of the dock.

The machinery consists of two balanced compound condensing horizontal steam-engines driving the fan spindles direct, each having a high-pressure cylinder 14½ inches diameter by 16 inches stroke, and a low-pressure cylinder 29 inches diameter by 16 inches stroke. The cylinders are placed at opposite ends of a framework and act on a two-throw steel crank-shaft, revolving in brass-lined bearings formed in girders spanning the frames at top and bottom. The high-pressure cylinder has an expansion slide-valve and gear complete, in addition to the main valve by which the degree of cut-off can be varied if desired.

The cylinders are connected by means of a cast-iron pipe with expansion-joint which has a copper pipe through it, carrying steam to the low-pressure cylinder, so that the exhaust from the high-pressure is to some extent re-heated on its passage to the low. An air-pump is placed in a line behind the high-pressure cylinder, being worked by a continuation of the piston-rod. There is a fly-wheel on the crank-shaft of the engine 7 feet diameter. There are two centrifugal pumps, each consisting of a cast-iron basin piece for the bottom of the pump wells, directrix and cast-iron fan

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6 feet diameter, connected to a steel vertical spindle by means of a cast-iron driving plate attached to the face by bronze screws. The bottom bearing of the spindle is cased in brass, and runs in a lignum vitæ strip bearing, fixed in the directrix casting, due provision being made for the circulation of the water. At suitable intervals in the wells, guide bearings are fixed for the spindle. There are two suction-sluices, one to each main pump-well, with cast-iron frames and doors. These sluices are worked by hydraulic cylinders, with a working pressure of 700 lbs. per square inch, which is supplied by the hydraulic-pressure system of the docks. There is one delivery wooden flap to each main pump well, having a cast-iron frame. There are two horizontal non-condensing expansive leakage pump-engines, each having a cylinder 8 inches diameter by 12 inches stroke. The engines work two sets of two-throw leakage pumps having barrels 16 inches diameter by 18 inches stroke. The position of the pump barrels is such that they draw from the dock under any condition of water-level. The steam is supplied by three single-flue multitubular boilers, each 6 feet 6 inches mean diameter by 21 feet 6 inches long outside, having one flue 3 feet 9 inches diameter terminating in eighty-nine tubes $3\frac{1}{4}$ inches diameter and 6 feet long, fifteen of which are stay tubes secured into both tube-plates. There are two sluices for main suction culverts, each consisting of a wooden door with cast-iron top plate, with a hydraulic lifting cylinder worked from the hydraulic system of the docks.

When the graving docks were completed, the pumps were tested and found to work well up to the requirements, having emptied the docks in 12 per cent. less than the stipulated time. Great trouble was experienced at first with the fly-wheels, which had a square motion, and after the engines had been at work for some 7 months, both gave out, cracking at the spokes. Heavier fly-wheels were consequently cast in Buenos Ayres, and the whole of the square motion disappeared.

At the time Congress decided upon the construction of the graving docks, they were much needed, there being no graving dock in the Republic where the naval vessels could be repaired, and the Author was asked by the Minister of War if it were possible to have one dock completed in $8\frac{1}{2}$ months, but this could not be done; still the matter was so urgent that eventually the Author, on behalf of the contractors, undertook to have one completed in $10\frac{1}{2}$ months, this being upon the understanding that temporary pumps would have to be provided for emptying the

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dock, as it was impossible to complete the permanent pumping station in the time.

When in Congress the Minister of War informed the House that the engineers had assured him that one dock could be finished in 10½ months, all the opposition to the construction of the graving docks collapsed. The West Dock was completed in 10 months from the date of the decree, and the East Dock, together with the pumping station, in 16 months. It should, however, be borne in mind that the entrance curves of the graving docks were already built, having formed part of the extra work ordered in connection with the North Basin; still the amount of work done during the 1 year and 4 months—which included some 56,464 cubic metres of rubble masonry alone—was enormous. The greatest credit is due to the Executors of Mr. T. A. Walker, who, under the direct management of Mr. C. H. Walker, brought the graving docks to such a satisfactory termination, thus enabling the concessionnaires and engineers to carry out successfully their undertaking.

## Cost of the Works.

The absence of any description of suitable materials within a reasonable distance of the works has naturally greatly increased their cost. The nearest places where stone could be obtained in the Argentine Republic were Hinojo and Tandil, the former 317 kilometres and the latter 330 kilometres from Buenos Ayres, and the railway carriage was so high when the works were commenced, that to procure stone from these places was out of the question. After much consideration Mr. T. A. Walker came to the conclusion that it would be more economical to purchase quarries and work the same in Uruguay; consequently a mole was erected at Conchillas, 48 kilometres from Buenos Ayres. About 5 miles of railway were laid down from the mole to the quarries, and from these quarries nearly all the rubble stone used on the works was procured, being taken over to Buenos Ayres in steam-barges. The opening up of these quarries has been a great benefit to the Argentine Republic, inasmuch as the Great Southern Railway Company have reduced the freight on the stone from Tandil to $2 gold per ton, the result being that stone can be obtained to-day at a far more reasonable rate. The sand was also brought from Uruguay, where it is found in great quantities and of the very best description.

With regard to the ashlar granite, the cost of working the same in the Argentine Republic, together with the railway freight,

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being so heavy, it was found to be more economical in the first instance to have all the ashlar sent out ready dressed from Cornwall.

During the construction of dock No. 4, the cost of dressing the stone in the Republic decreased considerably owing to the crisis; at the same time the quality of dressing so materially improved that ashlar could be obtained from Tandil as well dressed as that from England, while the stone itself was much harder. Under these circumstances Mr. Walker procured a great deal of the ashlar from Tandil.

The sleepers, which were of quebracho and urandai, were obtained from the Gran Chaco, while the cement, pitch-pine and iron, had all to be procured either from England or the United States.

The following are a few of the quantities of the work executed, together with some of the principal materials employed:—

| | | |
|---|---|---|
| Excavation | 5,523,138 | cubic metres. |
| Rubble masonry | 529,761 | ,, |
| Ashlar masonry | 11,185 | ,, |
| Piling in wharfing | 17,103 | ,, |
| Walings in wharfing | 10,562 | ,, |
| Brickwork | 62,500 | ,, |
| Concrete | 59,581 | ,, |
| Ironwork (warehouses and sheds) | 15,112 | tons. |
| Rubble stone | 1,342,000 | ,, |
| Sand | 376,715 | ,, |
| Bricks | 28,125,000 | No. |
| Pitch pine | 41,000 | cubic metres. |
| Cement | 87,000 | tons. |

Appendix V gives the cost of the works apportioned to the various docks and basins, buildings, railways, machinery, &c. The total amount, including interest on certificates, financing engineering and concessionnaires, being $35,626,822 gold, or £7,068,814.

In 1882 the tonnage coming to the River Plate was stated to be 1,000,000 registered tons, and upon this tonnage it was shown that the dock scheme, if properly managed, would be remunerative. Appendix III gives the number of ocean steamers that have entered the port of Buenos Ayres during the 6 years from January, 1892, to December, 1897, together with their respective tonnage, and from this Table it will be seen that the tonnage has more than doubled itself, being in 1897, 2,342,391 tons; while Appendix IV shows that of the 901 steamers with registered tonnage of 2,342,391, no less than 519 steamers, having a registered tonnage of 1,327,571,

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fly the British flag. The total area of land reclaimed from the river is 3,750,000 square metres, or 926 acres, of which 2,270,000 square metres, or 561 acres, have been made up more or less to quay level. After deducting the quays, together with the long strip of land on the river side, which was originally reserved for future dock extensions, and also that reserved for the proposed Central Railway Station, the amount of surplus land available for sale equalled 794,398 square metres, or 164 acres.

In June, 1888, a company was organised by Mr. Eduardo Madero, comprising many of the wealthiest men in Buenos Ayres. This company, supported by some of the banks in London and Paris, in the beginning of July made a proposition to the Government to purchase all this available land for the sum of $20,000,000 gold, or, say, £4,000,000. It must be remembered that this was a genuine offer, and made for land much of which was at that time flooded—if not always, certainly at high water. A second or opposition proposal was also made in July by Messrs. Carlos Lumb and Sons, who offered $22,500,000 gold, or, say, £4,500,000 for the same lands. These two proposals were referred to the Department of Public Works, who reported that the area of land to be sold amounted to 887,000 square metres, and that they valued the same at $80 m/n, or nearly £12 4*s*. 0*d*. per square metre, giving a total of $70,960,000 m/n, which, taking the exchange at 130 per cent. = $54,584,615 gold, or £10,830,300. In view of this report, Congress decided that the proposals should not be accepted, and that the land should be sold by public auction in accordance with the Port Works Law. Soon after, the crisis came, land depreciated in value, and consequently the offers were not renewed. Had the Government accepted provisionally either of these offers when made, the docks would have cost them nothing, as the first contract for the docks amounted to $20,000,000 gold, or, say, £4,000,000.

It must, however, be borne in mind that the land on the east and north sides of the docks has now nearly all been filled with dredged material to some 2 feet above quay level, that tosca has been tipped in the roads on the west side, while the storm-water drain, now being constructed by the Salubridad Works, has been carried as far as Calle Cangallo. When this is finished the whole of the land between Casa Amarilla and Cangallo, on the west side, will be free from river water, and it will be clearly seen that the land is really much more valuable to-day than when the offer of $20,000,000 gold was made for it.

In *La Opinion* of the 23rd July, 1882, the following appeared from the pen of an eminent Argentine statesman :—"The Port of

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Buenos Ayres, when it is realized in all its magnitude and united with our railways, will be the only seaport in which will concentrate the import and export trade of the Argentine Republic from Bolivia and Paraguay. It will be the key of our commerce and of our industry, and the centre of the greatest commercial movement in South America."

The Author knows that the statesman who wrote that prophecy, to-day is proud to see how it has been fulfilled, even more than he anticipated. The whole of the works since their commencement have been under the inspection of the National Department of Engineers, and the names of the chief engineers of the hydraulic works who have been more directly responsible for the same to the nation are:—Mr. F. Stavelius, M. Inst. C.E., from April, 1887, to April, 1889, and from November, 1889, to January, 1893; Mr. G. Dominico, M. Inst. C.E., from April, 1889, to November, 1889; Mr. S. E. Barabino from January, 1893, to January, 1894; and Mr. L. Taurel from May, 1894, to the present time.

The Author cannot conclude the account of these works without bearing tribute to the memory of the heads of the three firms who were so intimately connected with them, but who have not lived to see them completed. Mr. Thomas Andrew Walker died on the 25th November, 1889, Sir John Hawkshaw on the 2nd June, 1891, Mr. Eduardo Madero on the 31st May, 1894, and Mr. Harrison Hayter on the 5th May, 1898. No one regarded with greater respect and affection these men than the Author, and while missing their faces to-day, he feels, that in describing these works, which have been completed in the Argentine Republic, his firm and the representatives of the two other houses have striven side by side and brought to a successful issue, leaving as a monument to these men, what to Mr. Madero was his life work.

Since the death of Mr. Madero the affairs of the port works have rested in the hands of his two sons, Mr. Eduardo Belen Madero and Mr. Juan José Madero, who were associated with him from the signing of the contracts. The whole burden of the port works, however, has, since that time, fallen upon Mr. Eduardo Belen Madero, who has been assisted by Mr. Aurelio Berro, and these gentlemen have so ably managed the business that too much credit cannot be paid to them for the financial arrangements they have proposed in their negotiations with the Government, to the success of which negotiations, especially in the arrangement of 1895, the personal influence of Mr. Juan José Madero has contributed in no small degree.

The Author feels that the three firms have been nobly supported

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through all the difficulties of the last twelve years by General Roca, President of the Argentine Republic when the contracts were signed, and President now when the works are finished; Dr. Carlos Pellegrini, President during a portion of their construction; Dr. Quirno Costa, Vice-President, Mr. Emilio Mitre y Vedia, Assoc. M. Inst. C.E., Mr. George W. Drabble and Mr. R. W. Perks, M.P., and he wishes to take this opportunity to sincerely thank them all in his own name, and in that of his partner, for so greatly assisting in bringing the works to a successful termination, thereby cementing the good feeling and friendship existing between this country and the Argentine Republic.

The Paper is accompanied by drawings from which Plate 4 and the Figures in the text have been prepared.

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# APPENDIXES.

## APPENDIX I.

TIDAL OBSERVATIONS REDUCED FROM RECORDS BY AUTOMATIC GAUGE DURING THE YEARS 1890 TO 1894 INCLUSIVE.

| Month. | High Water. | | | | Low Water. | | | |
|---|---|---|---|---|---|---|---|---|
| | Level. | Time on Full and Change Days. | | | Level. | Time on Full and Change Days. | | |
| | | A.M. | | P.M. | | A.M. | | P.M. |
| | Ft. Ins. | Hrs. Mins. | | Hrs. Mins. | Ft. Ins. | Hrs. Mins. | | Hrs. Mins. |
| January | 4 0·2 | 5 10 | | 5 40 | 1 1·4 | 1 0 | | 0 30 |
| February | 4 0·4 | 5 30 | | 7 40 | 1 1·0 | 1 5 | | 1 35 |
| March | 3 10·6 | 5 50 | | 7 40 | 1 1·9 | 2 0 | | 0 55 |
| April | 3 9·0 | 7 0 | | 7 10 | 1 1·9 | 1 20 | | 1 35 |
| May | 3 6·7 | 6 40 | | 7 20 | 1 0·1 | 1 25 | | 1 5 |
| June | 2 11·5 | 7 10 | | 7 10 | 0 8·0 | 1 15 | | 1 45 |
| July | 3 1·8 | 6 30 | | 7 0 | 0 9·0 | 0 35 | | 0 55 |
| August | 3 4·0 | 5 20 | | 6 0 | 0 11·7 | 1 10 | | 1 45 |
| September | 3 2·6 | 5 20 | | 5 50 | 0 9·3 | 0 45 | | 1 55 |
| October | 3 5·7 | 5 0 | | 5 0 | 0 11·7 | 0 30 | | 1 15 |
| November | 3 8·5 | 5 30 | | 5 20 | 1 0·3 | 1 20 | | 1 15 |
| December | 3 11·1 | 5 20 | | 4 50 | 0 10·9 | 0 40 | | 0 55 |
| Average | 3 7·0 | 6 2 | | 6 33 | 0 11·6 | 1 5 | | 1 17 |

| Month. | Range of Tide. | Water Level. | Tidal Axis. | Difference between Water Level and Tidal Axis. |
|---|---|---|---|---|
| | Feet. Ins. | Feet. Ins. | Feet. Ins. | Feet. Ins. |
| January | 2 10·8 | 2 8·1 | 2 6·8 | +0 1·3 |
| February | 2 11·4 | 2 8·0 | 2 6·7 | 0 1·3 |
| March | 2 8·7 | 2 7·3 | 2 6·1 | 0 1·2 |
| April | 2 7·1 | 2 5·9 | 2 5·5 | 0 0·4 |
| May | 2 6·6 | 2 3·3 | 2 3·4 | −0 0·1 |
| June | 2 3·5 | 1 10·0 | 1 9·8 | +0 0·2 |
| July | 2 4·8 | 2 0·3 | 1 11·4 | 0 0·9 |
| August | 2 4·3 | 2 2·8 | 2 1·9 | 0 0·9 |
| September | 2 5·3 | 2 1·1 | 2 0·0 | 0 1·1 |
| October | 2 6·0 | 2 3·7 | 2 2·7 | 0 1·0 |
| November | 2 8·2 | 2 4·7 | 2 4·4 | 0 0·3 |
| December | 3 0·2 | 2 5·4 | 2 5·0 | 0 0·4 |
| Average | 2 7·4 | 2 4·05 | 2 3·31 | 0 0·74 |
| Year, 1890 | 2 5·5 | 2 4·1 | 2 3·4 | +0 0·7 |
| „ 1891 | 2 7·5 | 2 7·7 | 2 7·0 | 0 0·7 |
| „ 1892 | 2 7·8 | 2 5·4 | 2 4·8 | 0 0·6 |
| „ 1893 | 2 7·8 | 2 1·5 | 2 0·6 | 0 0·9 |
| „ 1894 | 2 8·5 | 2 1·5 | 2 0·7 | 0 0·8 |
| Average | 2 7·4 | 2 4·04 | 2 3·3 | 0 0·74 |

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TIDAL OBSERVATIONS—*continued*.—MONTHLY RECORD SHOWING THE NUMBER OF TIDES WHICH REACHED THE LEVEL ABOVE LOW WATER INDICATED AT THE HEAD OF EACH COLUMN.

| Year 1894. Month. | Below 1 Foot. | Between: 1 and 2 Feet. | 2 and 3 Feet. | 3 and 4 Feet. | 4 and 5 Feet. | 5 and 6 Feet. | 6 and 7 Feet. | 7 and 8 Feet. | 8 and 9 Feet. | 9 and 10 Feet. | Total No. of Tides. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| January . | 1 | 4 | 17 | 7 | 9 | 7 | 4 | 1 | 1 | 1 | 52 |
| February | 2 | 5 | 8 | 7 | 10 | 3 | 3 | 2 | 2 | .. | 42 |
| March . | 2 | 7 | 10 | 13 | 6 | 4 | 4 | 1 | .. | .. | 47 |
| April . . | .. | 7 | 10 | 11 | 11 | 5 | 3 | 1 | .. | .. | 48 |
| May . . | 5 | 2 | 12 | 10 | 7 | 6 | 3 | 1 | 1 | .. | 47 |
| June . . | 9 | 16 | 13 | 12 | 5 | 2 | .. | .. | .. | .. | 57 |
| July . . | 2 | 9 | 15 | 8 | 11 | 7 | 1 | .. | .. | .. | 53 |
| August . | 3 | 9 | 17 | 10 | 9 | 3 | 2 | 1 | .. | .. | 54 |
| September | 2 | 10 | 15 | 11 | 9 | 3 | 3 | .. | .. | .. | 53 |
| October . | 4 | 3 | 17 | 12 | 12 | 2 | 5 | .. | .. | .. | 55 |
| November | 2 | 6 | 11 | 13 | 14 | 7 | .. | .. | .. | .. | 53 |
| December | 2 | 7 | 14 | 6 | 11 | 7 | 6 | .. | 1 | .. | 54 |

NOTE.—The number of tides is affected by the wind, which frequently causes the river to rise or fall continuously during 24 hours; this may take place at any time, but generally coincides with the first and last quarters of the moon.

## APPENDIX II.

TABLE SHOWING CAPACITY IN CUBIC METRES, AND FLOOR AREA IN SQUARE METRES, OF WAREHOUSES AND SHEDS.

| Position. | Number of Warehouses. | Number of Sheds. | Capacity of One Warehouse or Shed. | Floor Area of One Warehouse or Shed. | Total Capacity in Cubic Metres. | Total Area in Square Metres. |
|---|---|---|---|---|---|---|
| | | | Cubic Metres. | Sq. Metres. | | |
| South basin . . | .. | 3 | 10,200 | 2,500 | 30,600 | 7,500 |
| Dock No. 1 . . | 2 | .. | 29,000 | 9,600 | 58,000 | 19,200 |
| ,, ,, . . | .. | 2 | 10,200 | 2,500 | 20,400 | 5,000 |
| ,, ,, . . | .. | 1 | 21,900 | 5,800 | 21,900 | 5,800 |
| ,, No. 2 . . | 2 | .. | 29,000 | 9,600 | 58,000 | 19,200 |
| ,, ,, . . | .. | 2 | 10,200 | 2,500 | 20,400 | 5,000 |
| ,, No. 3 . . | 5 | .. | 37,400 | 13,100 | 187,000 | 65,500 |
| ,, No. 4 . . | 4 | .. | 46,900 | 16,400 | 187,600 | 65,600 |
| Total capacity and floor area of all the warehouses and sheds . . | | | | | 583,900 | 192,800 |
| Deduct for passages say 10 per cent. | | | | | 58,390 | |
| | | | | | 525,510 | |

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## APPENDIX III.

OCEAN STEAMERS THAT ENTERED THE DOCKS AND BASINS DURING THE YEARS 1892-97 INCLUSIVE.

| Month. | 1892. | | 1893. | | 1894. | | 1895. | | 1896. | | 1897. | | Total No. | Total Registered Tonnage. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. | Registered Tonnage. | No. | Registered Tonnage. | No. | Registered Tonnage. | No. | Registered Tonnage. | No. | Registered Tonnage. | No. | Registered Tonnage. | | |
| January | 45 | 116,763 | 81 | 174,979 | 62 | 144,529 | 79 | 196,551 | 97 | 230,778 | 95 | 232,129 | 459 | 1,095,729 |
| February | 57 | 138,362 | 66 | 151,861 | 76 | 154,666 | 82 | 200,741 | 108 | 271,503 | 93 | 228,848 | 482 | 1,175,981 |
| March . | 50 | 122,011 | 76 | 164,666 | 77 | 190,152 | 81 | 199,869 | 116 | 282,663 | 91 | 232,681 | 491 | 1,192,042 |
| April . | 53 | 110,387 | 67 | 156,471 | 64 | 152,220 | 77 | 187,966 | 99 | 244,154 | 80 | 200,102 | 440 | 1,051,300 |
| May . . | 51 | 123,661 | 69 | 169,821 | 69 | 173,889 | 82 | 195,321 | 90 | 216,525 | 79 | 199,324 | 440 | 1,078,541 |
| June . | 59 | 135,361 | 62 | 145,179 | 48 | 123,912 | 79 | 185,497 | 88 | 217,742 | 72 | 197,388 | 408 | 1,005,079 |
| July . . | 63 | 137,845 | 74 | 187,337 | 69 | 162,659 | 95 | 219,133 | 92 | 227,857 | 74 | 189,989 | 467 | 1,124,820 |
| August . | 58 | 142,274 | 62 | 146,622 | 66 | 159,287 | 84 | 198,285 | 77 | 200,243 | 64 | 178,220 | 411 | 1,024,931 |
| September | 61 | 144,187 | 49 | 118,724 | 49 | 120,933 | 82 | 195,685 | 88 | 220,079 | 53 | 137,980 | 382 | 937,388 |
| October . | 48 | 107,902 | 57 | 134,571 | 61 | 134,236 | 96 | 219,710 | 70 | 181,823 | 68 | 182,834 | 400 | 961,076 |
| November | 66 | 147,524 | 63 | 151,300 | 80 | 197,432 | 106 | 248,816 | 90 | 224,882 | 60 | 164,802 | 465 | 1,134,756 |
| December | 78 | 182,797 | 72 | 179,088 | 76 | 182,022 | 103 | 243,189 | 92 | 235,291 | 72 | 198,094 | 493 | 1,220,481 |
| Totals . | 689 | 1,609,074 | 798 | 1,880,619 | 797 | 1,925,737 | 1,046 | 2,490,763 | 1,107 | 2,753,540 | 901 | 2,342,391 | 5,338 | 13,002,124 |

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## APPENDIX IV.

NATIONALITY OF OCEAN STEAMERS ENTERING THE DOCKS AND BASINS DURING 1897.

| Flag. | No. of Steamers. | Registered Tonnage. |
|---|---|---|
| British | 519 | 1,327,571 |
| German | 162 | 472,481 |
| French | 97 | 318,049 |
| Italian | 49 | 129,521 |
| Argentine | 36 | 38,889 |
| Uruguayan | 15 | 7,480 |
| Norwegian | 12 | 17,076 |
| Spanish | 6 | 19,324 |
| Belgian | 1 | 3,554 |
| Austrian | 1 | 2,708 |
| Brazilian | 1 | 2,400 |
| Dutch | 1 | 1,798 |
| Danish | 1 | 1,540 |
| | 901 | 2,342,391 |

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## APPENDIX V.

BUENOS AYRES HARBOUR WORKS.—COST OF WORKS.

| | $ Gold. | $ Gold. |
|---|---|---|
| *South Basin.*—River wall from south end to opposite Calle Belgrano and part of south lock | 2,203,391 | |
| Three iron sheds, Nos. 1, 2 and 3 | 326,468 | |
| | | 2,529,859 |
| *River Wall* from Calle Belgrano to foreshore at north end of work | .. | 2,026,346 |
| *Dock No. 1*, part of south lock and passage No. 1 | 2,891,713 | |
| Two iron sheds, Nos. 4 and 5 | 213,062 | |
| Two warehouses, Nos. 1 and 2 | 666,970 | |
| One iron shed with brick cellar | 250,373 | |
| Open sided shed | 33,556 | |
| | | 4,055,674 |
| *Dock No. 2* and part of passages Nos. 1 and 2 | 2,074,454 | |
| Two iron sheds, Nos. 6 and 7 | 213,062 | |
| Two warehouses, Nos. 3 and 4 | 677,590 | |
| | | 2,965,106 |
| *Dock No. 3* and part of passages, Nos. 2 and 3 | 2,400,517 | |
| Five warehouses, Nos. 5, 6, 7, 8 and 9 | 1,802,853 | |
| | | 4,203,370 |
| *Dock No. 4*, part of passage No. 3 and north lock | 3,035,135 | |
| Four warehouses, Nos. 10, 11, 12 and 13 | 1,700,523 | |
| | | 4,735,658 |
| *North Basin*, including entrances to graving docks | .. | 2,331,658 |
| *North Channel*, including beacons and buoys | .. | 4,272,476 |
| *Hydraulic Machinery.*—Machinery delivered in Buenos Ayres | 936,844 | |
| General work in buildings, hydrant chambers, pile staging for pipes, painting, etc. | 287,544 | |
| Timework account for men employed in the erection of the machinery | 228,961 | |
| | | 1,453,349 |
| *Railways*, including permanent way materials, laying and ballast of broken granite | .. | 916,723 |
| *Paving* of granite sets and macadam | .. | 683,182 |
| *Sluice* at dock No. 3 excluding machinery | .. | 62,965 |
| *Timber Gantries* for enclosing the site of the works and excluding the storm-water drainage | 333,628 | |
| Dam at northern entrance | 98,703 | |
| | | 432,331 |
| *Dredging* and other works in South Channel | .. | 418,538 |
| | | 31,087,235 |
| *Graving Docks*, general work | 1,134,800 | |
| Caissons | 71,822 | |
| Pumping engines | 50,805 | |
| Hydraulic machinery | 13,509 | |
| | | 1,270,936 |
| Interest on certificates | 873,553 | |
| 7½ per cent. engineering and concessionnaires on $31,087,235 | 2,331,551 | |
| 5 per cent. engineering on $1,270,936 | 63,547 | |
| | | 3,268,651 |
| | | $35,626,822 |

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## Discussion.

Mr. Preece. Mr. W. H. PREECE, C.B., F.R.S., President, said his first duty was to propose a vote of thanks to the Author for the care, industry, and clearness with which he had brought before the Institution the great work of which engineers were all so proud. They were proud to see work of that kind conducted in other parts of the world. Those who had travelled over the world could go nowhere without finding illustrations of the prowess and skill of the British engineer. Perhaps the most charming part of the Paper was the very graceful tribute that the Author had paid to those great minds which were the springs of that magnificent work.

Mr. Hawkshaw. Mr. J. C. HAWKSHAW regretted that the Author, being on his way to Buenos Ayres, was unable to be present; but he was glad of the opportunity of saying how much credit was due to him for the able way in which he had superintended the carrying out of the works, often under conditions of great difficulty, requiring much tact and consideration on his part. It was also a matter of regret that so many of those who were concerned at the beginning with the works had not lived to see them completed. He alluded more especially to Don Eduardo Madero, the concessionnaire; Mr. T. A. Walker, the contractor; Mr. Hayter and Sir John Hawkshaw, the engineers. The harbour had been known as the Madero port, and he hoped that the name of Madero would always be associated with it, because he felt sure that to his ability, his energy, and his foresight, the works owed their existence. Taking into consideration the size of the work—the work covering much ground—and having taken so many years to complete, the Paper had very few mishaps to relate, and it lacked some of the interest which was usually attached to a good account of a failure during construction. He attributed the freedom from accidents in a great measure to the good material which was met with throughout for the foundations; but he thought that credit was also due to the contractor for the careful way in which he had carried on his work, and for the abundance and excellence of the plant which he had put on it. The late Mr. T. A. Walker was never wont to stint the amount of plant he put on any work he had to do, and his nephew, Mr. Charles Walker, who had carried on the work since his uncle's death, had followed his example in that respect, and he

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hoped for his own sake he would always continue to do so. The material met with in the foundations was commonly called Tosca. It extended over a very large area in Argentina. It was the only formation met with over thousands of square miles south and west of the River Plate, immediately below the surface soil. It was a calcareous marl formed in an old estuary, probably from the drainage of an area very similar to that drained by the rivers which now fell into the estuary of the River Plate. Looked at from the point of view of an engineer who wished to make docks it had admirable qualities. It was easy to work and it would stand with a vertical face of 20 feet or more without any timbering for an indefinite length of time. With regard to the provision of locks, Mr. Révy, he believed, was the first observer who determined that there was a regular lunar tide in the River Plate. During the whole time in which he was engaged in the survey of the rivers Paraguay and Uruguay, and the estuary of the Plate, for the late Mr. Bateman, he took systematic observations of the tides. He gave the deductions arrived at from those observations, but not the observations themselves, in a great work which he published on the rivers Parana and Uruguay and the estuary of the River Plate, which he called "The Hydraulics of Great Rivers." Soon after the harbour works were begun, a self-recording tide-gauge was provided, and a regular record was kept of the tides from that time onwards. The Author had given a summary of those records in a tabular form in the Appendix. There it would be seen that the range of tide was 2 feet 7·4 inches, but the level of the water varied very much with the wind. When a strong wind prevailed for any length of time, and acted on the wide expanse of shallow water in the estuary, the tide rose far above and—what was more important for the docks—fell much below the normal height. It was the knowledge that that would be the case which determined the provision of locks. On the 2nd May, 1890, shortly after the south lock was open, the water fell to a level of 8·2 feet below zero, leaving only 13 feet 7 inches on the dock sill. The channel to provide access from the deep water in the river to the North Basin was the most difficult problem to be decided in connection with the work. There were many who thought such a channel could not be made, and if made could not be maintained. The late Mr. Bateman, however, was not one of those, and he was sure that the members would feel satisfaction that an engineer of his eminence should have also recommended a channel very much in the direction it now occupied, which channel had been made since and maintained.

Mr. Hawkshaw.



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Mr. Hawkshaw.

The full depth and width had been completed from the North Basin to its junction with the Riachuelo Channel. It was most unfortunate that the Government had not yet decided on the extension of that channel to deep water. There could be no doubt that it ought to be extended in a direct line to the deep water at the bar anchorage. Until the channel was completed to deep water, to the "bar anchorage," the works were so far incomplete. At the same time he could not help thinking that though the sum which the docks had cost was very large, it had been money well spent by the Government. The Government would get a handsome revenue from the docks provided with such a large amount of warehouse and shed space. There was no doubt that that was the paying part of the dock. In addition to that they would have the land which had been reclaimed, and which would go far when sold to recoup them for a large part of the capital expenditure. There was besides a large indirect saving to the country in the diminished cost of landing the goods from ships. It was reckoned that before ships could enter the docks the average cost of landing a ton of goods from ships in the "bar anchorage," and bringing them to the town, averaged about 10*s.* a ton. He could not say what the present cost was, but it was nothing like that amount, and there was a large indirect saving on that account.

The Hon. R. C. Parsons.

The Hon. R. CLERE PARSONS had read the Paper with much interest as he had been frequently in Buenos Ayres, and when he first landed there he had the experience, which was so graphically told in the Paper, of the manner of landing before the docks were built. He had also an additional adventure over and above what was described. When he got into the cart the horse became restive and insisted upon dragging it over an obstacle in the bottom of the river, and very nearly projected him into the water. Still, he landed safely. He thought it was the general opinion that the docks had been, and would be, of the very greatest benefit to the city of Buenos Ayres in the way of facilitating the trade of that port; but, besides this, they would be, and were now, of very great advantage from a sanitary point of view, in that they had covered the sandbanks in front of Buenos Ayres, which, when exposed at low tide, were extremely offensive. He noticed in the Paper that the Author drew attention to a paragraph which appeared in a Paper Mr. Parsons had prepared for the Institution some years ago upon the sanitary improvements of Buenos Ayres, with which he was connected. He wished it to be clearly understood that anything he said in

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regard to the matter was in no way finding fault with the construction of the docks, but simply as to the suitability of those works to meet the local requirements. The late Mr. Bateman, as was probably well known, had prepared an extensive dock scheme for Buenos Ayres, and his idea was that the docks should not be enclosed with gates, but that they should consist of a basin open to the inflow and outflow of the tide. His views were based upon the lengthy experiments which were carried out by Mr. Révy, whom Mr. Hawkshaw had referred to. Those experiments clearly showed that the rise and fall of the tide, except under abnormal circumstances, was only about 3 feet, and that was confirmed in the Appendix to the Paper. The depth of the river also from Buenos Ayres for 40 miles did not exceed, curiously enough, 21 or 22 feet, and Mr. Bateman argued that if those abnormal falls in the tide took place, and vessels took the ground, they might as well ground in the docks where the bottom had been made level and soft, as in what was called the deep water, where the bottom was uneven and not of uniform hardness; and the saving which would be effected in the cost of the docks by dispensing with the use of dock gates would be very considerable. The Paper showed clearly that it was absolutely necessary to keep the water of the Riachuelo out of the docks, because the water of that river, in consequence of having slaughter-houses and factories of various kinds on its banks, the refuse of which was discharged into it, was an extremely offensive fluid. Mr. Bateman provided in his scheme that there should be gates which would merely prevent the entrance of that water into the docks, but which would not be capable of supporting any considerable water pressure. Those gates would be of comparatively small cost. His scheme provided for the construction of a large basin parallel to the outer wall shown on the plan instead of being parallel to the town, as the docks had been constructed. There was to be an entrance into it nearly opposite the Customs House, and the channel was to run in practically the same direction as that adopted, and the water of the River Plate would flow into the large basin and out again. Inasmuch as the rise and fall of the tide was 3 feet per day and the dock 21 feet deep, the whole of the water in that dock would practically be changed twice every week. The estimate for that large basin, he need hardly say, was very much less than the cost of the docks as constructed, and he could not help thinking that it would have answered all practical purposes, and the results would have been as good as those of the costly docks which had been

The Hon R. C. Parsons.



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The Hon. R. C. Parsons.

constructed. Mr. Bateman, in addition, with the view of changing the water in the docks, which was of great importance, suggested in his report that the storm-waters which fell over a large area of that great city should flow into the basin, and in that way assist materially in changing the water. It was seldom understood in this country what a large amount of water fell in Buenos Ayres during storms. The storm-conduits which were under that city were more like railway tunnels than conduits—most of them were 14 feet by 12 feet—and they were to discharge into the basin. The amount of water which would flow during a storm down those conduits into the basin would be 127 cubic metres per second, or, in other words, there would be 457,000 cubic metres of water per hour flowing into the basin, which was no trifling amount. During one storm, three-eighths of the total volume of water in the docks would be changed. That was a very considerable advantage, and might be obtained by the use of that storm-water; but the principal reason why it was proposed that the storm-water should be taken into the basin was to save the enormous expense of carrying it into the river outside the basin. That point had been entirely omitted from the Paper. The cost of the storm-water conduit shown in the plan was about three-quarters of a million sterling, and about half of it had already been constructed. Three-quarters of a million sterling would more than pay for all the sewers throughout Buenos Ayres, and that was one of the most potent reasons why it was proposed that the storm-water should be discharged direct into the basin. At the time this was proposed the Argentine Government were very short of funds, and it was important that the money should be saved. The construction of the docks was, however, proceeded with without any decision being arrived at, and it was not until they were almost completed that the intercepting storm-water conduit was commenced. Another interesting point with reference to the cost of these works, which amounted to seven millions sterling, was the enormous outlay on the reclamation of land. It was stated in the Paper that certain offers had been made for the purchase of that land which amounted to four millions sterling; but he would say that those offers were made at a time when everybody in Buenos Ayres was excited about the value of land. It was in the prosperous times, when everybody thought that land would rapidly increase in value. Everybody believed that they had only to speculate in land to treble their money annually, and many people told him what a fool he was not to bring out any capital he possessed and treble it annually in Buenos Ayres.

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That boom lasted for about 2 years, and then came the collapse, and since that time land upon which that enormous expenditure had been made for reclamation had been practically unsaleable. It had been put up to auction again and again, and small lots had been sold at about 12 to 14 gold dollars per square metre. The cost of filling up the land came to nearly 4 gold dollars, and that was after the deduction was made for the cost of dredging out the channel and depositing the material in a suitable position, so that it would not be washed into the channel again. That expenditure of capital was lying dead, and it was a question how long it would remain so, because to cover that reclaimed area with buildings would take years, and in the meantime it was doubtful whether the expenditure was warranted. That led to the point, should not the area of the docks be similar to the area of land to be reclaimed, and was any land gained from the river beyond that of the nature of a land speculation? In point of fact the works described were to a great extent a land speculation which had not been very successful. The Southern Basin, as would be seen on the plan, was a basin with a timber wharf constructed of pitch-pine, at which a very large amount of trade was carried on. Vessels did not mind in the least grounding there when the abnormally low tides took place, and it was a question whether the docks, if they had been constructed of timber—not pitch pine, but Quebracho Colorado, a native wood, the life of which was practically unknown, as it lasted so long—would not have answered as well. Many of the wharves on the Riachuelo were constructed of that timber, and alongside of those wharves a very large amount of trade was carried on. The cost of a wharf of that description was about 257 gold dollars per lineal metre, while the cost of the concrete wall was 600 gold dollars per lineal metre. Not long since he was consulted by the Great Southern Railway of Buenos Ayres with reference to the construction of a large dock on the south side of the Riachuelo. He had carefully investigated the matter, and it appeared to him perfectly clear that a dock with wharves constructed of that native timber would come to about one-third of the cost per lineal metre of those described in the Paper. That dock was now being carried out by the railway company, and he believed it would pay far better and be more easily accessible for shipping than the docks referred to. He would very much like to have the views of the Author on the points to which he had alluded, as, doubtless, they had been carefully considered, and were matters of considerable

The Hon. R. C. Parsons.

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The Hon. R. C. Parsons.

interest and importance, not only to Buenos Ayres, but to other places. Before he sat down he should like to congratulate the Author upon a remarkable intervention of Providence, to which allusion had been made. He must say that all the time he was in Buenos Ayres he was never favoured in the way the Author had been. Many a time he had wished that some providential way of getting out of his difficulties would arise, but he was sorry to say he always had to wriggle out of them as best he could unassisted by any similar occurrence.

Mr. Baggallay.

Mr. H. C. BAGGALLAY had been in Buenos Ayres two or three times during the last few years, and had had opportunities of seeing this great work under construction. He had never seen any work more thoroughly carried out than that work had been by Messrs. Walker; it was magnificent, but he agreed with the Author that less costly works would probably have answered the purpose. The first question he would have liked to have asked the Author had he been present was, what was the reason for having lock-entrances at each end? The docks, as arranged, were, he would not say parallel to the shore, but they more or less took up the whole frontage. To his mind the disadvantage was that half of the traffic must, of necessity, cross swing-bridges to get to the other side of the dock. That, of course, was the case in most English docks, because it could not be helped; circumstances had made it necessary to construct the docks in that particular way. For instance, the West India docks comprised three parallel docks, and beyond them again there were the Millwall docks, all crossed by swing-bridges, and the inconvenience to traffic was very considerable. In a case like Buenos Ayres there was nothing to tie the design in any way, and it would have been perfectly feasible to design docks on any particular plan. He presumed that that particular position was more or less compulsory and beyond the control of the engineers. It was known that with South American Governments, if the Minister said a dock was to be in a particular place it had to be put there. He did not quite see why docks of more or less the same size should not have been constructed about parallel to the South Basin. In fact, it might be said that the approach to the dock was something like the passage in a Pullman car as compared with that in a corridor carriage. He looked upon the work as a Pullman car with a passage down the middle. The docks might have been slewed round and the approaches made from one end, and then all the rails would have gone down on either side of those docks; and

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for the same amount of accommodation the water area might then have been half the width, and there would have been no crossing swing-bridges. He looked upon the docks simply as the beginning of a much greater system. They happened to be of almost the same size as the Victoria and Albert docks in London; they were not quite so long, but they were exactly the same width, and he calculated they would accommodate nearly the same amount of trade. Referring to Appendix III, headed "Ocean steamers that entered the docks and basins during the years 1892–7 inclusive," he presumed that it meant the Buenos Ayres docks. Mr. Baggallay.

Mr. HAWKSHAW observed that the Author meant the Buenos Ayres docks. Mr. Hawkshaw.

Mr. BAGGALLAY said it was a curious fact that in 1897 in the Victoria and Albert docks 877 ships entered, with the registered tonnage of 2,160,000. In the Buenos Ayres docks, which were practically of the same size and very much the same in shape, 900 ships (almost exactly the same number) with a tonnage of 2,350,000 entered. That being the case he presumed the docks were full, because it was found that more work could not be done in the Victoria and Albert docks. That led him to the question of bridges and cranes. It was found at the Victoria and Albert docks, where there were five engines of a total I.HP. of 1,000 to work the hydraulic power, that sometimes the power failed. The docks at Buenos Ayres were provided with only two engines of 450 I.HP. each. That was easily added to, but what he wanted to point out was that that great power of 900 I.HP. was divided between only two engines. He found practically that it was necessary to have always at least three units. With two units, when one engine was out of repair, only half the power was available; whereas, if the power was divided into three there was not more than one-third out of gear at one time. He presumed the engines could be worked in halves, so that the inconvenience might not be quite as bad as might appear at first sight; but even then it was very often necessary to stop an entire engine, although the halves could be worked independently. Therefore he thought it would be necessary before long to add hydraulic power for a large number of cranes as well as for hydraulic bridges. When the docks were extended, as marked on the plan, more docks would be made parallel to those now existing, and then the inconvenience of the railway traffic over the swing bridges would be greater. There was another reason why he should have suggested putting the docks in the other position, and that was that a lock at either end added very much to the working Mr. Baggallay.

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Mr. Baggallay. expenses of the dock-masters and the men connected with the locking. Had both the locks been at one end, one supervision would have been sufficient for both. With regard to the question of getting a current of water through, he thought that might just as easily have been got over by a small canal which might have had permanent bridges over it approaching from the north side, if both of the locks had been put on the south. He could not quite understand from the Paper the real reason for making the northern channel. It was stated that with this direction of the channel it was much easier to keep clear of silt. That was apparent, but it appeared to him that it was absolutely necessary to keep the south channel clear whether it cost much or little, because that was the only approach to a very large docking arrangement on the Riachuelo and its branches. Therefore it would be absolutely necessary to maintain the south channel. It did not seem that there was much economy in making a better channel which could be kept clear at a cheaper rate than the south one, if both had to be kept clear. He might be mistaken on that point, and it might be the intention to allow the south channel to silt up and to make another approach. With regard to the length of the locks, he noticed that the main lock on the south side was only 443 feet long, whereas the other lock was 508. It seemed to him that those lengths were very short for the present day, when it was found that Liverpool, Barry, and nearly all the Dock Companies in England, were lengthening the locks up to between 600 and 900 feet. The entrances at the Victoria and Albert docks were 550 feet long, and ships now had to be sent to Tilbury, where the entrances were 700 feet in length, because they could not get through the Victoria and Albert locks. It was under the serious consideration of the Committee whether they would not have to make a new lock. At the West India dock, some years ago, a new lock had to be put in, because the dimensions of ships were growing so fast. It could not be said that the ships which traded in the River Plate would of necessity be shorter than those which came to London; for he found, on working out the number of ships at Buenos Ayres in 1897, with their tonnage, that they averaged actually 100 tons more than the ships which came into the Victoria and Albert docks. Therefore the ships were larger. It was known they could not be deeper, because the river at the present moment was only 21 feet deep. The ships which came into the Victoria and Albert Docks drew as much as 26 feet; therefore it must be taken out in length or in beam. Then he noticed the southern lock was only

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65 feet wide, whereas it was found necessary now in England to make most of the locks much wider than that. In fact, all the new locks were being made 80 feet, and even more. Mr. Baggallay.

Mr. HAWKSHAW pointed out that the north lock was 82 feet wide. Mr. Hawkshaw.

Mr. BAGGALLAY said he was referring to the southern one. On the north side the lock was longer, 508 feet long, 82 feet wide and 22 feet deep. The one on the south side was 443 feet by 65 feet and 21 feet 9 inches deep. It would be interesting to know why the basin on the north side which approached the larger lock was made 2 feet 6 inches shallower than the docks themselves. At Ensanada la Plata the docks were dug down deeper, because there were no lock-gates, and when the river became low the ships dropped as into a hole, and it was not necessary to have the approach as deep as where the ships were lying; but at Buenos Ayres the water was kept up with lock-gates. He did not quite understand why the basin was made only 21 feet deep. He saw that a part of the channel was already dredged to over 22 feet, and he was perfectly certain that before many years Buenos Ayres would not be content with an approach of only 21 feet. If it was impossible, as it might be, to maintain a channel to sea deeper than 21 feet, then he was pretty certain that before many years they would have a ship-canal to Buenos Ayres. A place which was practically the only large port for an enormous country which was doubling and trebling its trade every few years, would not be content with ships that only drew 20 feet of water. With regard to the increase of ships, he noticed in the Port of London during the last 10 years that the average size of ships had increased 24 per cent. —that was taking all the ships coming into the London docks increased 28 per cent. in 10 years. It was hardly likely that the people of Argentina, who were very advanced in many of their views, would be content to allow only 21 feet as the approach to their capital, for if they did not improve it, they knew that the trade would have to go down to Bahia Blanca and to other places where there was plenty of deep water. Even the docks themselves, he thought, might with advantage have been made a little deeper. He had worked out the details given in the Paper, and he found that for every foot in depth the cost would be £70,000. When £7,000,000 were being spent on docks the spending of another £70,000 or £150,000 in making them 2 feet or 3 feet deeper would be money well spent, because after the docks were once made the additional cost of deepening them was very serious. Even in the West India docks, where there Mr. Baggallay.

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Mr. Baggallay. was 25 feet of water, they were putting out false quays in order to get deeper water. He should like to ask one question with regard to the dredging in the channel. It was stated that the estimate was about 800,000 metres to keep the channel clear. He took a metre to be about 2 tons—say 1,600,000 tons. Of course, in the Tyne about 2¾ million tons were dredged, and in the Clyde 2¾ million tons, and in the London docks a good deal more than ½ million tons were taken out of the docks in addition to what was removed from the river. Therefore it did not seem to him a very large expenditure, compared with the magnitude of the work, to have to dredge 1½ million tons to keep the channel clear. If that would keep the channel clear a little more dredging would deepen it. It seemed to him that the first consideration would be to get a better approach up the river, either by deepening or by making a ship-canal, as the land on the side of the river was very low and of an alluvial character, which could easily be excavated. The cost would not be great.

Mr. Meldrum. Mr. S. J. MELDRUM thought that in the allocation of praise it might be well to remember that before Messrs. Hawkshaw and Hayter, before even Mr. Bateman had approached the question, there was a design prepared by Messrs. Bell and Miller, of Glasgow and Westminster, at the request of the Argentine authorities, which design was to a very large extent adopted by Mr. Bateman. In addition to the abstract statement in the Paper that the design was settled after considering the various previous schemes, he thought it ought to be put on record that the original design for these docks was that by Messrs. Bell and Miller, in whose office he had received his early training, about 25 years ago. He remembered Mr. Bell telling him that his original design had shown what was now described as the north channel, but after due consideration he had concluded that it was economically impossible to keep open such a channel, and he therefore resolved that the only possible economical channel was the one leading to the Riachuelo. It had been mentioned that the cost of keeping open the northern channel was not so very great, but he fancied if any attempt was made to deepen it to the requirements of modern ships the difficulty would be much increased. He was in Buenos Ayres during the period of exceptionally low tide mentioned in the Paper as having occurred in 1890, when for more than 24 hours the water was several miles distant from the town, and when the area exposed was used as a promenade by thousands of people. Serious damage was, he believed, at that time done to vessels lying in the channel

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entrance and also to some of the temporary work. It would be interesting to know whether the level of the water in the docks was well maintained during this period. Mr. Meldrum.

Mr. L. F. VERNON-HARCOURT congratulated Mr. Hawkshaw upon the completion of the work in which he had been most intimately concerned from the very commencement. The Author had stated that the whole of the water could be changed in the docks by directing the tidal current through them. The whole of the water, however, could not be thus changed, because the water was kept up to a certain low-water level; but no doubt there would be a great advantage in that current going through the docks for scouring the passages at locks and renewing the water. The Author had stated as the result of some float experiments, that the current through the docks was a good deal better than had been expected. The velocity obtained depended very much on what kind of floats were used, and where those currents were observed. In the docks themselves the current could not be very great; but in the passages and through the locks it would be considerable. It was to be regretted that if a lock of 82 feet was considered necessary, which probably it would be in the present day, the passages between the docks were not also made of the same width, because a vessel that required an 82-feet lock would be only able to get into the northern dock, and not into the others. Only the upper portion of the dock wall was given on the Plate in the Paper. The section of the dock wall was an important matter, because that made a large difference in the cost of the docks. The Author must be congratulated on the way that he got over a difficulty in putting in the foundations of one of the sills of the northern lock, namely, his use of a cylinder which he sunk to the lower stratum of tosca, by which he was able to pump above the running sand, and therefore without displacing it. Everyone who had had to do with docks, or almost any other engineering works connected with water, knew that if running sand were pumped up, it was impossible to tell how much one might be undermining foundations at a distance. Another thing worthy of notice was the subway which was put underneath the north lock; and certainly if a watertight subway could be arranged in that way, he thought it was preferable to the usual plan of having a groove down the side of the lock, across the invert, and up the other side. Where possible it would be certainly more convenient, although it might be more expensive, to have a subway for the various pipes which had to go across a lock severing property from the mainland. Thus at the West India docks, where he had superintended the con- Mr. Vernon-Harcourt.

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Mr. Vernon-Harcourt.

struction of docks, grooves were provided in the outer lock for the gas- and water-pipes, because there were locks at each end cutting off the Isle of Dogs. In the Paper most of the quantities were given in metres, and he thought it would have been advisable, as most of the figures in the Minutes were in feet, to make it clear in the Plate that water-levels were in metres. The arrangement made by the contractors with regard to the dredging was another point worthy of notice. It was generally supposed that if a contractor arranged to dredge a channel of a certain size, it would suffice to measure that channel in place, to ascertain that the contractor had done his work; but at Buenos Ayres they were more fortunate, because the dredging was not measured in place, but measured by what was actually brought up, assumed to be reduced in bulk as if it was in place; and certainly that was measuring the material to the greatest advantage, for all material dredged which was not deposited in the barges was excluded, although the determination of the actual bulk of the dredged material in place seemed to have given rise to a great deal of difficulty. It was unfortunate that the sills were not made rather deeper, because 22 feet was given as the depth of the sill below low water in the north lock; and adding to that the small tidal rise, which seemed to average about 2 feet 6 inches, with a maximum of 5 feet, there was only 27 feet as the depth over the sill. That seemed to be rather small as a maximum during spring tides, and he thought it would be an advantage if the North Basin could be carried down at least as low as the sill of the north lock.

A definition of the nature of tosca, which had an important bearing on the security of the foundations, and some indication of the regimen of the River Plate in respect of the sediment it brought down, would assist in elucidating the Paper. The proportion of 67 lineal yards of quay per acre of water area in the Buenos Ayres docks, was similar to that of the East and West India, and the Victoria and Albert docks in London; but the proportion of quay was considerably larger at Liverpool, Hull, and several other English ports. The high water-level of a "Santa Rosa," reaching 8 feet 3 inches above high water of spring-tides, was evidently caused by the heaping up of the waters of the out-flowing river by a strong southerly wind; and the very low water-level of 8 feet 2 inches below low water of spring-tides must be attributed to the reverse action of high northerly winds, driving the river water out to sea. Accordingly, instead of stating "that the level of the tides varies considerably, owing chiefly to the effect of the

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wind" (p. 191), it would appear more correct to say that strong winds blowing up or down the river had much more influence on the level of the River Plate than the small tidal oscillations on that coast. Mr. Vernon-Harcourt.

Mr. J. C. HAWKSHAW remarked, with regard to the provision of locks, that a vessel grounding in the River Plate, where the bottom was perfectly soft, was a very different thing from a vessel grounding in a dock with a very hard bottom, when the ship was perhaps half-loaded or just unloading. He did not think it would be safe to ground in the docks with a hard bottom. There was really a good current through the docks now from the North Basin to the South Basin, and the gates, he believed, were not shut regularly. The gates were there as a provision in case of any sudden fall in the water, so as to enable the water to be held up in the docks. He looked upon the land as something to the good, beyond the revenue from the docks which ought to pay a very good interest on the expenditure. When the works were half finished, the Chairman of the Harbour Trust made a statement at the Annual Meeting that the return to the Government from port dues and other charges produced a gross income equal to 3·84 per cent. on the total expenditure to the end of 1892 of 3½ millions sterling, and at that time only a portion of the warehouses had been constructed. It was the warehouses and sheds that really paid the interest on cost, and there was no doubt when they were all in working order a very good revenue would be obtained. With regard to the lock-entrances at both ends, when the docks were designed the Government insisted that access should be made from the Riachuelo channel. When the question of channels came to be looked into, it was considered that the Riachuelo channel was not the best direction for a channel, but that one ought to be made in the line of the present north channel, which was more in the line of the current in the river. The Riachuelo channel had never been dredged or maintained to the full depth—it had really never been completed, whereas the other channel had been completed through the most difficult part—the shallow part—and there ought to be much less difficulty about the other end of it, because there was very little dredging to do there. The water was deeper, and if the one end could be maintained, there ought to be no difficulty in maintaining the other. With regard to the dimensions of the docks, it must be remembered that the date of the first report was 15 years ago, and it was during the progress of the works, before the north lock had been begun, that it was thought desirable to increase its Mr. Hawkshaw.

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Mr. Hawkshaw. width. Possibly if the work was to be commenced now, a still further increase would be recommended in the South lock. He thought it should be borne in mind that the widths were settled 15 years ago. With regard to the depth of the channel, at the present moment there was not 21 feet of water at the entrance to the River Plate opposite Monte Video, and so there would be very little use in making the channels deeper until something was done to what was practically the bar of the estuary. Opposite Monte Video one had often to steam through the mud for an hour or two together.

Mr. Dobson. Mr. J. M. DOBSON, in a written reply to the Discussion, remarked that from the plan of the late Mr. Bateman, *Fig. 16*, it would be seen that the scheme proposed was, as stated in the Paper, very different in many great and important points from the one which had been carried out. With reference to the range of tide at Buenos Ayres, in order to avoid any misunderstanding which might arise regarding the figures given in Appendix I—they being average levels—he had prepared a diagram showing the actual variations during the month of December 1894. From *Fig. 17* it would be seen that the tidal axis itself experienced extraordinary variations, so that high water on one day was frequently lower than low water on the following, and *vice versâ*. This variation greatly facilitated the navigation of the River Plate so far as the depth of water was concerned, although it was a factor which could not be depended upon as to time. As to the statement that Mr. Bateman's reason for preferring an open basin was because he considered that if vessels grounded in the outer roads they might as well ground in the docks, he could only say that he was exceedingly glad that such a scheme was never carried out; since for large steamers to ground in the bar anchorage, where the mud in most cases was very soft, was quite different to ships grounding on the hard tosca in the docks. Referring to the Riachuelo, Mr. Parsons had stated that the Paper clearly showed that it was absolutely necessary to keep the water of this river out of the docks, and had referred to some gates suggested by Mr. Bateman which were not merely to prevent the entrance of the stream into the docks, but would be capable of supporting any resistance. It was difficult to understand to what Mr. Parsons referred, as it almost seemed as if he thought the outer or flood gates of the south lock were continually closed, and were not of sufficient strength to stand the small amount of pressure against them, there being nothing to prevent the water from entering the docks a north end. In the Paper it was stated that the flood gates

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Mr. Dobson.

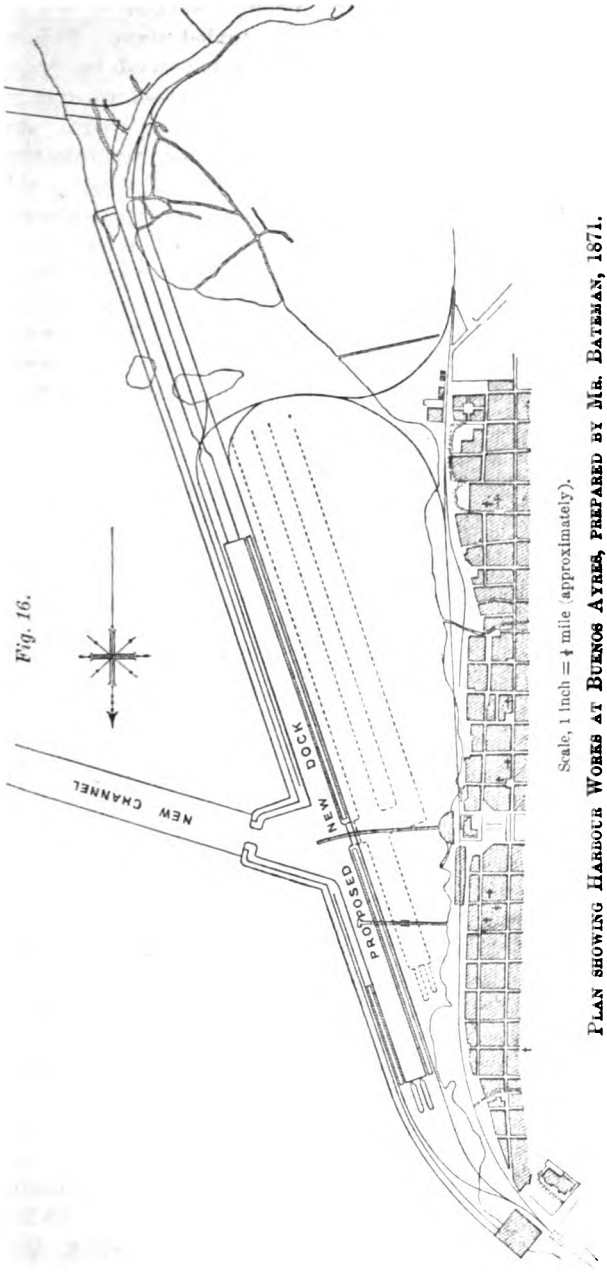


*Fig. 16.*

Scale, 1 inch = ¼ mile (approximately).

PLAN SHOWING HARBOUR WORKS AT BUENOS AYRES, PREPARED BY MR. BATEMAN, 1871.

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Mr. Dobson. at the south lock were used to prevent the water of the Riachuelo from entering the docks when in a turbid state. This occurred when the tide was very high and accompanied by heavy rains. The water of the Riachuelo then became backed up, and ran with the water from the River Plate up the South Basin. As a rule, however, the water of the Riachuelo did not run into the docks, but into the River Plate through the south channel. The gates in the north and south locks were only closed when the water fell to zero, by which means a depth of 23 feet 9 inches was always retained in the docks, and consequently vessels were always kept afloat. Respecting the cost of Mr. Bateman's proposed scheme, it was only necessary to study the plan and section. As a scheme, it was naturally a costly one to construct, more especially the outer wall, and it would in no way compare with the docks,

*Fig. 17.*

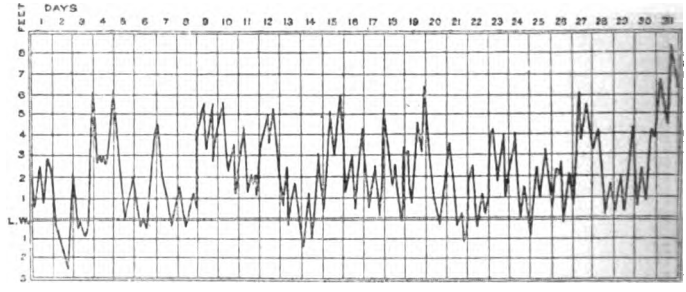


DIAGRAM OF TIDES DURING DECEMBER, 1894.

warehouses, and graving-docks as built. The section of Mr. Bateman's basin, *Figs. 18* and *19*, showed stone walls, and not timber, as would be inferred from Mr. Parsons' remarks, and a pitched slope, which, in section, was shown to be 21 feet 4 inches below low water, while the depth of the dock was only 20 feet below low water, and not 23 feet 9 inches, which was the case in the docks now constructed. As to the storm-water conduits which were intended to be discharged into the proposed basin, and which discharge it was estimated would amount to some 457,000 cubic metres of water per hour, the late Sir John Hawkshaw and Mr. Hayter were strongly opposed to the storm-water drains being discharged into the docks, on account of the large amount of sewage and other material which came down those drains. At the conduit at Calle Garay there was always over 18 inches of sewage for a great distance in the open cut during the whole

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time the Author was in that district, while opposite the inter- Mr. Dobson.
cepting storm-water conduit, which had now just been completed, as far as Calle Cangallo, there was at present a long bank of material some 18 inches thick — let it be called what it may — of a most offensive character, and dangerous to the health of the city. The Author felt sure Mr. Parsons could not realize what came down these drains, or he never would have advocated discharging them into the docks. It had also been stated that the docks were constructed and the progress of the construction was continued without any consideration as to the storm-water conduit being commenced. Everything was done by Sir John Hawkshaw and Mr. Hawkshaw, before and after the commencement of the works, to show the necessity of at once constructing the storm-water conduits. The government instructions. distinctly were that the dock engineers should not make any provision for drainage, as that was in other hands; but Mr. Hawkshaw, knowing that the works would block some of the main outlets, brought the matter in 1885 before Mr. Bateman's representative in Buenos Ayres; and it was perfectly easy, had it been thought advisable, to have raised any objection to the proposed dock plans during the 12 months they were under discussion; while in the memorial to government which Don Eduardo Madero sent when the plans were presented, dated 14th December, 1885, appeared the following: "Culverts. Several of these for discharging rain-water exist along the shore, fronting the area of land to be reclaimed from the river. A permanent tunnel that will take these waters to the river by the northern

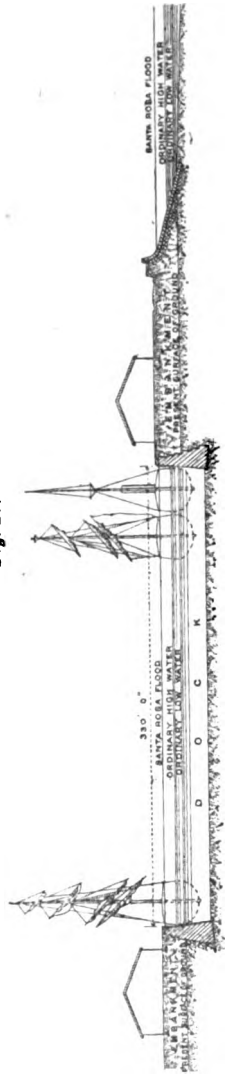


*Fig. 18.*

SECTION OF PROPOSED DOCKS AND RIVER-WALL.
Scale, 1 inch = 64 feet.



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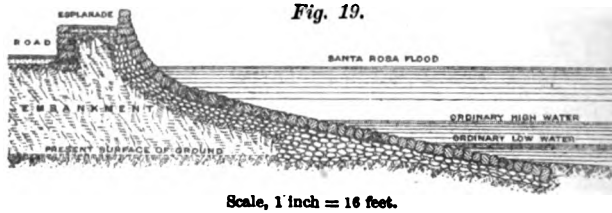
Mr. Dobson. end of the works must therefore be constructed. As there would not be time to construct this tunnel before the building of the docks begins, the constructors for these will have to form a temporary drain for the water that flows between Brazil and Venezuela streets. But in order to finish the harbour works within the time stated in the specification, it is indispensable that the forementioned permanent tunnel be finished within 2 years after the approval of the plans. On this point my engineers have spoken with the director of the sewerage works, the matter offering no difficulty." Surely in no way, therefore, were the dock engineers to blame, because the tunnel or conduit was not constructed during the execution of the port works, and remained uncompleted to-day, when the port works were finished. Mr. Parsons further referred to what he termed "a rather interesting point with reference to the cost of these works, which amounted to £7,000,000 sterling, which was the enormous outlay

*Fig. 19.*




Scale, 1 inch = 16 feet.

SECTION OF RIVER-WALL.

on the reclamation of land," and he went on to say that the land had been put up to auction again and again, and small lots had been sold at about 12 gold dollars to 14 gold dollars per square metre, and that the cost of filling up the land came to nearly 4 gold dollars, after the deduction was made for the dredging. These statements were misleading, and the cost for making up the land totally incorrect. In the first place, it was of great importance that all work carried out by engineers should show some result; and the principle so common in Holland, of carrying out works in the construction of which valuable land was reclaimed, land which, in many cases, represented the cost of these works, was a principle it would be well always, when possible, to keep in view. It was needless to say that on every count it would be seen that Mr. Parsons was in error. In the first case, had the land cost 4 gold dollars, or 16*s.* per square metre to make up, and all been sold for $12 to $14, or £2 7*s.* 7*d.* to £2 15*s.* 6*d.* per square metre, that would have left £1 11*s.* 7*d.*

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to £1 19*s.* 6*d.* per square metre; and taking the 296·5 acres or 1,200,000 square metres filled at even £1 11*s.* 7*d.*, the lower price, it would equal £1,895,000. But the land did not cost $4 to make up; on the contrary, as stated, "the land was filled with dredged material," each square metre of land requiring about 5 cubic metres of material to bring it up to quay level. As the difference of price to bring this material ashore, instead of depositing it in the river, amounted to 0·3107 gold dollar, or 1*s.* 3*d.* per cubic metre, therefore the cost of filling up each square metre of land was $0·3107 × 5 = say 1·55 gold dollars, or 6*s.* 3*d.*; this deducted from £2 7*s.* 7*d.* or £2 15*s.* 6*d.* gave £2 1*s.* 4*d.* and £2 9*s.* 3*d.* respectively, or a total of £2,480,000 and £2,955,000. It must be borne in mind that the government only sold the land at the price of 12 gold dollars to 14 gold dollars because they were urgently in want of money. Moreover, at the present time a large area of land had been let on the east or river side of the docks for 1 gold dollar, or 4*s.* per square metre per annum, and this was considerably better than selling it for 14 gold dollars per square metre. Mr. Parsons had further stated that this enormous capital was lying dead, and that it was a question whether that expenditure was wanted at all. To prove the fallacy of such an argument, the outer wall was required for the works, and was not necessitated on account of the filling; and surely to bring material ashore at a cost of 0·3107 gold dollar, making up land which, selling even at 12 gold dollars to 14 gold dollars per square metre, gave a profit of from 2·09 gold dollars to 2·49 gold dollars per cubic metre, was infinitely better than throwing it into the river, which the contractors were compelled to do at present, because there was no place to deposit it. Moreover, it might be well to notice that in Mr. Bateman's scheme referred to, a large area of about 750 acres was enclosed, and the excavation from the docks could never have filled the land proposed to be reclaimed. With reference to the South Basin, Mr. Parsons had stated that he thought it was a question whether the docks, if they had been constructed of timber, not pitch pine (hardwood, no doubt, was meant)—the life of which was practically not known, it lasted so long—would not have answered as well. If the docks had been built of hardwood timber, the works would not have been half finished at the present time. The fact of building the South Basin wharfing of pitch pine arose from the difficulty in obtaining hardwood of suitable sizes within the time fixed for the completion, which was very short; considering that the South Basin was commenced in July, 1887, and opened in

Mr. Dobson.



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Mr. Dobson. January, 1889, the length of wharfing completed being 1,135 yards—while the completion of this section also necessitated the construction of 1,732 metres of timber wharfing in the river-wall. There was no doubt whatever that, when admissible, works such as the South Basin wharfing had much better be built of stone, because the life of pitch pine was very short in this country, elm rotted almost as quickly, and quebracho, while difficult to obtain in suitable sizes, cracked and twisted with the sun; so much so that the Author was exceedingly glad when the government agreed, after much discussion, to alter the construction of the outside river-wall from timber to stone. The large dock on the other side of the Riachuelo was not to be carried out in timber, it having been decided to be unsuitable. In reply to the remarks made by Mr. Baggallay, the Author desired to state that, owing to the conditions existing at the time the contract was made, it was necessary that the works should be commenced at the south end, and none of the docks could have been used until all had been finished, if there had not been a lock at the south end. It was not considered that the south channel was laid down in a line that would serve the docks when completed to the best advantage; and as long ago as 1885 Mr. Hawkshaw had reported that he did not consider two deep-water channels were necessary. At the same time it was thought that, from the intersection to the Boca, a shallow channel would always be needed to serve the shipping in the Riachuelo, consequently the line of the north channel was laid down as considered best, and the engineers stated that to make two deep-water channels would be throwing money away. The government decided as follows:—Art. 3. "That the director of the engineers of the nation having stated in his report to the President, dated 26th August, 1881, that although at first sight the opening of a northern channel appears unnecessary, since the Riachuelo one can be used, still it is convenient to have two to expedite traffic, avoid useless goings and comings, and in the possible but improbable case that one of the channels become obstructed by the sinking of any ship, the other would be available, as is generally accepted in the construction of works of this nature, which was also taken into consideration in the cabinet meeting of 4th December, 1884; and, further, the dredging of the northern channel having been proposed by the engineers of the works, of whose competency the government has the highest official testimonials, the executive agrees with the statements made herein." Further, it was always understood that, when

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the north channel was completed, all the large steamers would enter the docks at that end, land their passengers in the North Basin, and use docks Nos. 4 and 3 for loading and unloading cargo, as naturally they would not run the risk of grounding if there were an exceptionally low tide. For this reason it was decided by the government to make the north lock 82 feet wide, although really 65 feet 7 inches was ample for any ships now coming, or likely to come for many years, to the River Plate. When the South Basin was opened in January, 1889, the M.M.S. "Orenoque" came up the south channel, as stated in the Paper. This channel was in the same condition then as it was to-day; the steamer grounded on the bank, and there was great difficulty in getting her off. The Royal Mail Company, the Veloce Company, and the Messageries Maritimes Company were waiting for the north channel to be completed in a direct line to deep water before they would allow their large steamers to come up to Buenos Ayres, and all this strongly supported the north channel having been laid down in the right direction. No inconvenience whatever arose from the locks and passages themselves, the only trouble occurred when the steamers endeavoured to pass through the locks and passages, with their own machinery, and at a rate which was quite prohibitive, instead of being warped through or tugged, as was done in any other port. There was no doubt that the docks were the beginning of a much greater system, as Mr. Baggallay had remarked, but any extension of the docks, in the Author's opinion, would not be at the south, but at the north end. The manner in which the basins and docks had been constructed had answered admirably, because, as soon as the South Basin was completed and opened, it brought in a revenue, and so on consecutively with docks 1, 2, 3. Docks constructed as proposed by Mr. Baggallay, with one entrance, never could have been flushed in the same manner as the docks of the capital, which could be dealt with so easily, as described in the Paper. With regard to the hydraulic power, the Author agreed with Mr. Baggallay's statement respecting the advisability of having one lay-by engine; but when the contract was framed it was not intended to carry the pipes down the South Basin, nor to have anything like the number of cranes, etc., that had been erected; for instance, in the nine new warehouses there were no less than 36 cranes and 36 hydraulic lifts, which were not contemplated. Had the Author been present at the Institution he would have further explained that the government had another hydraulic engine-house on the Riachuelo lying

Mr. Dobson.

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Mr. Dobson. unused and falling to pieces, and a number of cranes which had hardly been worked at all; and when it was found that more hydraulic power would be required, the Author proposed that the engine there should be put in order, and the cranes taken down, altered and re-erected on the South Basin. In consequence the hydraulic power had been thus increased. The engines of the port of the capital form practically four separate units; but even now, such had been the increase of the trade, the power was insufficient; consequently the Government were going to erect another pair of engines at the north end of the works. The fact of having additional power and cranes would therefore explain the difference between the Victoria and Albert docks and the docks of the capital, because the power of the Riachuelo engine was 125 H.P., making with the two engines of 450 H.P. each, a total of 1,025 H.P. With regard to the length of the locks, Mr. Baggallay had overlooked the fact that, when it was necessary to close the lock-gates on account of the water being below zero, no large vessels could come up or go down the channel, and when they could come up the locks were always open. Only vessels that could pass down the channel when the water was below zero were locked in or out, hence there was no necessity for having locks of very great length; the only advantage in having a long lock being that more than one small steamer could be taken in or out at the same time. As to the remark that if the docks had been put at one end and only one lock built, it would have saved working expenses, this matter was not lost sight of when the docks were planned; but many evident advantages had to be set aside in favour of the all-important point of providing the best possible entrance to the port. With regard to the depth of the North and South Basins, which was 21 feet 3 inches below zero, there was really no object in making these basins deeper than the channel, which was maintained at 21 feet; and the reason that the docks were made 2 feet 6 inches deeper was in order that the vessels should be kept afloat when the river fell to zero. With regard to the channel being down to 22 feet below zero on a length of 10 kilometres, it would be impossible to keep a channel down to 21 feet throughout its entire length unless it were dredged to a greater depth; and the instructions which the Author had given to the constructors were, that they should dredge not less than to a depth of 22 feet, nor more than 23 feet, and by this means it was possible to keep the channel down always to 21 feet. Should the north channel ever be maintained to 23 feet, it would involve a large amount of dredging between the bar

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anchorage and Montevideo, as there was at present in many parts of the course, and in front of Montevideo, as stated by Mr. Hawkshaw, only 21 feet below zero. With reference to Mr. Meldrum's question as to the level of the water in the docks in 1890, on the date to which he referred, the level of the water should have been zero or low water, giving 23 feet 9 inches in dock No. 1, which was the only dock opened; and this proved the advantage of having lock-gates, as the level of the water in the river, as stated in the Paper, was 8 feet 2 inches below zero, consequently all the steamers in the South Basin, which was tidal, were aground. Replying to the remarks made by Mr. L. F. Vernon-Harcourt, the whole of the water could be changed, as stated in the Paper, because, although the water was not allowed to fall below zero, the gates were left open sometimes for days together, and only closed when the necessity arose, either for sluicing purposes or for retaining the water at the zero level, when a low tide was expected. With regard to the floats referred to, it would be hardly necessary for the Author to state that proper floats were used to find the rate of the current; they each consisted of a flat piece of wood, to which a line 15 feet in length was attached, having at its lower end a sack filled with shavings, and loaded with sufficient stone to sink it to the proper depth, so that the float was controlled by the lower current, and not appreciably affected by the wind or surface current. The current was naturally greater through the passages than in the docks. The floats were tried at almost every time of tide. The current through the docks was such that the bottom of the lock sills at both ends, the bottom of the passages, and the docks down the centre, were perfectly free from silt. As to the depth of the sills in the north lock, to this the Author had already replied, but it might be as well to add that the tendency to-day was to build larger ships, but drawing less water, for the navigation of the River Plate.

Mr. Dobson.

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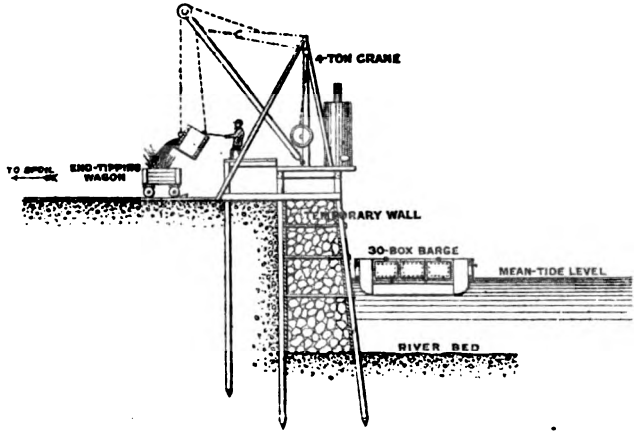
## Correspondence.

Mr. Buchanan. Mr. GEORGE C. BUCHANAN thought that a more detailed account of the execution of the works, of the plant and material used, and of the difficulties encountered, would have proved useful and instructive. It appeared that 87,000 tons of cement were used, but it was not stated what specification was adopted, nor whether many tons were rejected. It would also be interesting to have a short description of the dredging plant engaged, and the cost per cubic metre of dredging and depositing. He agreed that the best plan of disposing of the hard tosca dredged from the channel

*Fig. 20.*




would have been to fit barges with iron boxes. At Dundee 4,000,000 tons of dredged material had been so disposed of in the last 30 years, and 78 acres of ground had been reclaimed from the river. The dredgers discharged into bottomless box punts, each of which contained thirty boxes having a capacity of 43 cubic feet each. The punts when loaded were towed to the reclamation wharf, and the boxes were lifted individually by a 4-ton derrick crane and tipped into wagons (*Fig. 20*). The total cost amounted to 8*d.* per ton, made up as follows:—Dredging, 2½*d.*; towing, 1½*d.*; depositing, 4*d.*

Mr. Caland. Mr. P. CALAND, of the Hague, asked why the depth of the bed of the basins, locks, docks and channels had been limited to 21 feet,

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when, as was generally known, in all large seaports a depth of 30 feet was now considered necessary. He did not understand the object of the "storm-water-conduit." It was admitted that in stormy weather the tide carried down a large amount of impurities, and according to Fig. 2 these would be carried by the conduit into the city without any remedy being provided. Would it not be well to consider the question of placing this "conduit" outside the locks, so as to prevent the foul water from being carried into the city? In other respects, the works had been carried out in a serviceable and able manner, and proper provision had been made to meet any difficulties that might arise in connection with them. Mr. Caland.

Mr. CHARLES COLSON had found in dealing with wet foundations, and especially in running water, that many difficulties could be met, and a thoroughly sound foundation insured by the use of concrete bags. The bags should not be too large, and of a strong and close material. The ordinary cement bag was a very useful type as regarded size, strength, and convenience of handling. The bags should not be more than two-thirds full, and the ends should be sewn over, not tied in the ordinary way, in order that they might take a flat form which would admit of their being packed closely and in regular courses with practically close joints. If the bags were filled and tied at the mouth they took a more or less circular form, and the result in the work was not so satisfactory. In dealing with an extensive and deep fissure from which a large volume of water was flowing, and where the conditions were such as to render it impossible to use bags in the ordinary way, a large and strong canvas sheet was placed very loosely over the hole, the edges of the sheet being tried up well above the water; into this sheet the concrete was deposited. The concrete, in sinking, carried the slack of the sheet deep into the fissures. By this means all washing of the concrete by the flowing water was effectively prevented, a sound foundation was made, and a very serious inrush of water was checked to such an extent as to give pumps control of the leakage. The engineers were fortunate in having to deal with a site which admitted of the basins being advantageously planned as regards the relation of water area enclosed to length of wharfage—that was, they were able to adopt dimensions of length to width which provided ample room for manœuvring vessels with both side-wharves occupied by vessels, and at the same time gave the greatest lineal length of wharfage in relation to the area enclosed. It not infrequently Mr. Colson.

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Mr. Colson. happened that it was impossible to adopt the most advantageous relation of width to length, with the result that there was an excess of water area and a loss of lineal wharfage, and, what was perhaps of considerably more importance in some cases, a loss of land area. With regard to the timber jetty work, it appeared to have been recognised that the use of timber would not be ultimately economical, and that the life of such structures would be short. It would be interesting to know if this was due chiefly to the worm; any further information as to the ravages of this enemy of timber structures would be most valuable. It would also be interesting to know what method was adopted in depositing the concrete in the dock floor, where it was substituted for the brick arch as originally designed. In such a position as a dock-floor horizontal laminations were highly objectionable, and were, in fact, a source of weakness. To meet this objection he had adopted a method of depositing the concrete as blockwork *in situ*, the areas of the blocks being so arranged that they might be completed to the full height required, or to as great a height as possible, during the working-day. Particular attention was given to the act of depositing, so as to ensure homogeneity; all the concrete was trimmed into place and thoroughly rammed. Great importance was attached to this operation; it was not deferred until a layer of concrete was completed and then applied to the upper surface only, but was continuous; the layers, 12 inches to 15 inches deep, followed each other as quickly as possible consistent with thorough consolidation, so that each succeeding deposit might be incorporated with the preceding one. All the longitudinal vertical joints were made practically radial, and all joints were rendered with cement as the adjacent block was formed. The work was commenced at the centre, or key block, so that the floor became practically an arch.

Mr. Crahay de Franchimont. Mr. H. CRAHAY DE FRANCHIMONT, of Paris, feared that the Argentine Government would regret, later, the use of timber, to so great an extent, not only for the quays but also for the lock-gates and for the warehouses, as the conditions under which the works were maintained would become more and more onerous as time advanced. In particular the employment of timber for the lock-gates conduced to make the gates very heavy (more than 205 lbs. per square foot of the surface of the gate); further, the employment of rollers, the efficiency of which tended to become less after some time, and which, being situated at the under edge of the gate, were difficult to inspect, to maintain in good order, or

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to replace. He imagined that at Buenos Ayres the lock-gates, on the outer side of which were the North Basin or South Basin respectively, were not liable to be subjected to wave-action of importance, and should that be so it would have been advantageous to have made them of iron or of steel; not only because then they would be buoyant and consequently without need of rollers, but further because it would have been practicable to place the actuating gear in the upper part of the gates, where it could be easily reached, have rendered the gate-leaves independent of one another, and have done away with the necessity for chains. In a Paper on the third basin at Rochefort[1] would be found an example of the method described, which had given full satisfaction. Mr. Crahay de Franchimont.

The use of timber in the warehouses, and of zinc for the roofs, appeared to be very undesirable, especially in hot climates, not only on account of the preservation of the goods warehoused but also on the score of danger from fire. With the growth of commerce and general progress at the present time, such structures should be of cement, with iron or steel joisting, &c. (*ciment armé*); and all large dock warehouses should be built in this way, at least so far as regarded the floors and the roof, continuous masonry being reserved for the vertical walls and for the foundations, whereby structures might be obtained uninfluenced by variations of temperature, easy to cleanse and to disinfect, incombustible, moderate in first cost, and economical in maintenance.

From experience he was not surprised to find that the method of measuring the dredged material in the vessel, barge or other, allowing a reduction for increase in bulk, had, in this instance, given rise to grave difficulties in the regulation of the contractors' accounts. It could not be otherwise, for when millions of cubic yards were shifted, the least divergence from the correct estimate of the percentage per unit of this reduction must seriously affect the financial conditions, and be of vital importance to one or other of the contracting parties. In the question of dredging it was chiefly necessary to consider whether the material to be dredged was quiescent, that was, a layer not easily disturbed, or whether it was of a shifting character, affected by the current and constantly varying in amount. As regarded the first case, it appeared that measurement by means of cross sections pre sented no difficulty; in the second case the mode of measurement might be based on the net cubic capacity of the vessels, hold or

[1] Annales des Ponts et Chaussées, May 1897

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Mr. Crahay de Franchimont.

compartments; or if by weight, by the reading of gauges marked on the vessel at bow and stern. The last method would have been the best to adopt at Buenos Ayres, where the matter in suspension was of considerable amount, and where the material dredged was of three different characters.

Under circumstances such as the above, in France, preference would be given to carrying out the work by day labour. If the Argentine Government had adopted this course it would have found itself, after the completion of the primary dredging of the channels, &c. (which would certainly require constant attention to keep open), in the possession of the valuable plant requisite for the future maintenance of the channel from the anchorage roadstead to the port, &c.

He agreed with the Author as to the desirability of adopting sliding gates at the entrances to the graving-docks, especially in a newly created port such as this, which had not grown gradually, but where the works were entirely new and were on so large a scale, whereby such great facilities of working were attained. In this case the additional cost of such an arrangement, and the provision of space for the lateral recesses for the gates, would have been a small matter in so large a total outlay. It must be remembered that this form of gate, which had actually been designed for some of the French ports, had not yet come into current practice. The use of ship caissons was general and was likely to be continued, as although their working took more time, they were very simple; and if requiring more labour, this labour could almost always be utilized in the working of a graving-dock, both for warping the vessel into the dock and for securing it. The execution of these two graving-docks, the first in 10 months and the second in 16 months, including the machinery, reflected great credit upon the energy of the engineer and others concerned.

Mr. Pilkington.

Mr. WOODFORD PILKINGTON remarked that the sub-divisional arrangement of the docks, involving drawbridges, had been criticised; but what would have been the result if, when on one side of such a length of structure, it were necessary to ferry across—to say nothing of the obvious advantage of the bridge piers as counterforts to such a length of wall, perfect alignment being difficult to maintain at such length under such circumstances? Again, as to the length of the locks, it was impossible 12 years ago to provide in the original design for radical changes as works progressed so as to be exactly up-to-date. Even now, by

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waiting and partial discharge of cargo, the largest ocean steamer afloat could be made to pass the south lock. As to the value of the land filled with dredged material, the Author had stated that, had the land been sold to a syndicate in the year 1888, the whole value of the works as at that time proposed would have been paid for—that was possible; but a refractory syndicate, finding the speculation a doubtful one, might have fought the Government inch by inch, and so have been able to prevent the completion of the river front; and the now magnificent esplanade had been paid for out of profits. He considered the land reclaimed would yet be worth the cost of the works. The splendid river frontage was worth £4,000,000 to a great city like Buenos Ayres from an artistic and sanitary point of view. Land reclaimed and filled with dredged material told its own tale. Docks cut out on one side and land filling on the other was characteristic of the only sound method of design for harbour works. Lock- and dock-gates were used, it appeared, against the judgment of the engineers where sliding caissons or wheel caissons might have been employed. Gates for graving or other docks or locks were now out of the question if caissons could be employed. There was a loss of ¼ hour every time the gates were opened or closed. Again, a locomotive could be run over the folding bridge of a sliding caisson; nothing could be run over gates. Practically a swing-bridge was necessary in addition. Again, with a graving-dock a sliding caisson could be made to shut the water in as well as shut the water out—that was to say, a wet dock or a dry dock was available at will, and this was a very important alternative. The caisson berth or recess added perhaps £1,000 to the price of the dock, but the value of the alternative might, in the event of an accident, be worth £5,000 a day. The meeting faces of the stone-work with caissons was the real difficulty. These had to be mathematically true and of polished granite. Floating or ship caissons were useful in their place, but did not affect the former question.

Mr. Pilkington.

Mr. James Price considered the Paper an interesting account of the successful execution of works rendered especially difficult by natural causes. The completion in such good time was noteworthy as an instance of what might be accomplished in a country where labour was "free," owing to the number of different nationalities rendering labour combinations impossible. He, however, doubted if it would be found possible (considering the fine, light mud carried down by the River Plate) to keep the docks and channels

Mr. Price.

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Mr. Price. clear by dredging alone at reasonable cost. With respect to the docks, he thought the current of 850 feet per hour or ¼ foot per second would not be sufficient to prevent deposit, particularly along the walls, and suggested that it was probable that large roller sluices on Stoney's principle would be required at each side at the ends of the line of docks to produce effectual scouring. With respect to the approach channels, he thought use might have been made of roller sluices to make a sluicing-pond of the Riachuelo River, the tidal water being used for scouring out the South Channel, making it the main approach, and the sluicing pond itself being scoured by leaving the sluices full open during the heavy floods which occurred at frequent intervals in Buenos Ayres. This would confine maintenance dredging to the more sheltered positions, which would be an advantage for a situation so liable to "pampero" gales. It would be interesting to learn if there were special reasons for using pitch-pine piles with elm fenders for wharves, as, even if the water was free from worms, such piles would not be durable considering the high temperature and dry air of summer and the heavy rains of winter. It appeared that more durable work at no greater expense (labour being taken into account) could be constructed by using either Greenheart or Jarrah piles, placing fender piles of the same material 50 feet apart. He suggested that information as to the dredging plant used would be of interest, particularly as to the cost of dredging "tosca"; also if all dredged material was used for land reclamation, or if hopper barges were used where deposit areas were found which would not cause injury to the ports of La Plata or Montevideo.

Mr. Robinson. Mr. JOHN ROBINSON observed that schemes for harbour accommodation at Buenos Ayres were being discussed when he was there in the years 1872–3, and that Sir John Hawkshaw, Son and Hayter had concurred in the view expressed by the late Mr. Bateman, that the best site for the harbour was in front of the city, along the foreshore of the Rio de la Plata, between the gasworks and the Boca, or mouth of the Riachuelo. At that time tidal basins, without gates or intervening locks, were advocated; but it would have been, he thought, a mistake if these had been carried out, for the reasons given by the Author. The practicability of maintaining a dredged channel between the proposed harbour and water, having a depth of 3½ fathoms, which was of vital importance to the scheme, was questioned by many who favoured the formation of a port at Ensenada, 28 miles from

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Buenos Ayres. The problem, however, appeared to have been satisfactorily solved by making the north channel in a south-easterly direction, which was evidently the right one, being the same as that of the run of the river and as that proposed by Mr. Bateman. The cost of maintenance might be somewhat high, but the benefits to be derived from a free and open communication with the sea far outweighed the expense. He would be glad to know what effect the new channel had upon the currents, and if there was any difficulty in its navigation when the dreaded "pampero" from the south-west was blowing. With regard to the width of the south lock and the three passages between the four docks, he asked why were they made only 65 feet 7 inches instead of the same as the north lock, namely, 82 feet? 65 feet 7 inches appeared to him rather narrow for a modern dock, taking into consideration the tendency to build vessels of increasing size. And why were the dock walls battered, seeing that the midship section of modern cargo vessels was nearly rectangular, having the corners rounded off at the bilges, or with the widest part above the bilges? The concrete and rubble outer or exterior wall, substituted for the timber one, was to be commended, and he would like to know the cost of each. The late Mr. T. A. Walker had tested a sand and mud pump at Barry Dock before sending it out to Buenos Ayres, and he would be glad if the Author would describe the pump, and state if it answered the purpose for which it had been used; and if he would give the quantity of sand or mud it was capable of depositing in a given time behind the tosca filling at the back of the outer wall. Mr. Walker had designed a special side-tipping wagon for tipping mud or silt behind marl filling, also from temporary wooden staging, at Barry Dock. Although the material was soft when tipped, it became firm when the water was drained away from it. As the sand and mud pumped at Buenos Ayres would be in a more liquid state than that tipped from side wagons at Barry, he was desirous of knowing if any special arrangements were made at Buenos Ayres for draining the water away, and how soon it became firm? The Author did not mention the kind of mortar used in the rubble walls, whether lime or cement. Mr. Bateman contemplated using a cement to be made from tosca, which was something like the marl and chalk of England. Mr. Robinson.

Mr. G. DE THIERRY, of Bremen, while fully admitting that a site in the immediate vicinity of the city must necessarily be most advantageous, could not, on the data given in the Paper, concur in Mr de Thierry.

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Mr. de Thierry. the desirability of the general arrangements adopted. The locks had been constructed with the object of preventing vessels of deep draught from taking the ground at times of abnormally low water-level, and without regard to the ordinary variations in water-level due to tide, which were unimportant, averaging only 2 feet 7·4 inches. Although the estimate given on p. 172 showed that, from a financial point of view, it was more economical to construct two locks than to lower the bed of the whole harbour and to carry down the foundations of the quay walls to a correspondingly greater depth; this consideration did not show that the adoption of locks was the best method in the interests of shipping and the port, especially keeping in view the development of modern ship-construction, as this arrangement limited henceforth the depth for vessels entering the docks to 22 feet plus the depth for the time being of the water-level above low water. When it was remembered that vessels of deep draught were, according to the statement in the Paper, likely to be affected by the "lowest water-level" condition but seldom, not on an average once a year, it would have been sufficient to have carried down the foundations of the quay walls to a greater depth in one of the docks; and as regards the bed of the harbour, to take that out to the greater depth at, say, only the berthing sites of the vessels in this particular dock, so that vessels of the greatest draught would then be quite ensured against the possibility of taking the ground. The cost would, with this arrangement, and keeping account of the working expenses of locks, undoubtedly be less than that for the locks. As even now at periods of "lowest water-level," vessels of over 21 feet draught could not enter the harbour, he could not see the advantage of the expensive locks, and considered that by their adoption, apart from the increase in cost of the whole arrangement, the capacity for development of shipping was liable to be crippled in an unnecessary manner. There appeared also an insufficiency of turning space. The outer harbour or North-west Basin alone allowed space for large vessels to turn. Large vessels, for instance, entering Dock No. 2 must make a detour of nearly 1 mile before they could turn, and it would appear that this must be a considerable disadvantage in using the harbour. The difficulties described by the Author in connection with the estimation of the amount of dredged material pointed to the desirability that work of this character should be executed under administration by the commissioners rather than by contract.

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Mr. W. B. TRIPP had been engaged on the staff of the late Mr. Bateman when occupied on the works for the improvement of the city of Buenos Ayres, at the time that the projects for the improvement of the harbour were being considered by the Government; and he thought it might be of interest now to place on record some facts in connection with the intense interest shown by the community at that time as to the best kind of harbour scheme to be adopted. This question had at that time been debated for some fifty years, and was by no means settled; in fact the wide divergence of opinion on the subject must have caused considerable embarrassment to the Government in their consideration of the different schemes proposed. The excitement of the public mind was indicated by the number of "port schemes" brought forward, which were so numerous that, to use the language of one of the newspapers, "the projects presented for its construction are numberless, and not only professional men but everybody in Buenos Ayres that appraises himself a bit has considered it his duty to have a project of his own." Some of these schemes were, as might be expected, of an ephemeral character, others were better supported. The principal part of them might be divided roughly into four classes as follows, viz.:—Class 1.—The formation of a harbour with docks, &c., on the foreshore in front of the city, somewhat after the plan proposed by Mr. Bateman; the works being either in one or more sections, with greater or less depth of water, and with dredged channels of various lengths, according to circumstances. Class 2.—Schemes embracing some of the features of Class 1, combined with an outer harbour in the estuary some miles distant from the city. The outer harbour being enclosed either by means of floating breakwaters forming a harbour of refuge in the outer roads, with telegraphic communication with the inner harbour in the city, or by means of a dock wall enclosing a sufficient space and possessing railway communication with the shore. This class was humorously compared at the time to a saucepan, the handle being represented by the railway communication with the shore. Class 3.—Schemes for the utilization and improvement of the natural port of the Boca del Riachuelo, to serve all purposes of a port for Buenos Ayres. Class 4.—This final class embraced schemes for the formation of ports and harbours at eligible positions at a somewhat greater distance from the city of Buenos Ayres, such as Ensenada or Punta Lara. Some of these projects had been actually carried out to a greater or less extent of completion since that time; when the difficulties and uncertainties connected with the practicability of the proposed works, especially

Mr. Tripp.



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Mr. Tripp. of the formation and maintenance of the dredged channel, caused so much discussion of the subject, and were the origin of the unpreparedness of the community to accept Mr. Bateman's scheme, which, like those of other great men, seemed in this case to have been before its time. That extensive speculation, however, doubtless cleared the air, so to speak, and prepared the way for the final acceptance of the magnificent works described in the Paper.

Mr. Wheeler. Mr. W. H. WHEELER considered the results given by the Author as to the dredging interesting, even if they only proved how little reliance was to be placed on small scale experiments in matters of this kind. The method of measurement adopted as between the Government and the contractor must have been as unsatisfactory to the one side as to the other, and was certainly one that could not be recommended for adoption. The quantity of sand removed in the barges as compared with the quantity measured *in situ* was not given; but, with the mud, it appeared that, while the measurement by means of boxes showed the quantity as measured in the barges 11·65 per cent. greater than that of the material *in situ*, the actual working gave an opposite result—the quantity as measured in the barges being 32 per cent. less than the quantity measured in the channel, the difference being accounted for by a certain portion of the lighter material being carried away in suspension by the water. A similar result occurred in the dredging of the new ship channel to New York, where the quantity obtained from the measurement of the dredged channel was 27 per cent. greater than that obtained by measuring the material in the barges. These cases however, were exceptional, the barge measurement as a rule exceeding the measurement *in situ*. Thus in the dredging at the Albert Dock entrance on the Thames, where the material removed was soft mud, the barge measurements amounted to four times the quantity shown by the sections. Where the material to be removed was soft mud extending to a great depth and for a considerable distance above and below the part of the channel to be dredged, and where there was a strong current, the measurements as shown by the sections could not be taken as a guide as to the quantity to be removed. Thus for the approaches to Grangemouth Dock, the quantities were taken by the contractor as shown by the sections at 432,000 cubic yards. After dredging for 18 months and removing 650,000 cubic yards as measured in the barges, the measurement *in situ* showed that the section of the channel had only been increased to the extent of one-half that indicated by the plan, the mud being carried into the excavation nearly as

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fast as the channel was deepened. It would be of service if the Author could add to the figures already given the ratio that the measurement of the material *in situ* bore to the weight. In dredging operations two statements of the quantity of material were necessary, one in cubic yards to indicate the extent of the intended improvement of the channel as shown by the sections, and the other in tons actually raised, for the purpose of checking the power developed by the engines, and the coal consumption. His experience showed that in hard boulder clay a cubic yard represented 1·48 barge tons, and in soft mud 1·58 tons, and this practically agreed with data obtained from other sources. Mr. Wheeler.



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# ANNUAL GENERAL MEETING.

25 April, 1899.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

The Notice convening the Meeting was taken as read, as well as the Minutes of the Annual General Meeting of the 26th April, 1898, which the President was authorized to sign.

The Report of the Council upon the Proceedings of the Institution during the Session 1898–99 was read, the Statement of Accounts being taken as read.

After consideration, it was resolved,—That the Report of the Council be received and approved, and that it be printed in the Minutes of Proceedings.

The Scrutineers reported the election of the Council for 1899–1900 as follows :— [1]

*President.*

Sir DOUGLAS FOX.

*Vice-Presidents.*

James Mansergh.
Sir William White, K.C.B., D.Sc., LL.D., F.R.S.
Charles Hawksley.
John Clarke Hawkshaw, M.A.

*Other Members of Council.*

James Barton, B.A.
Horace Bell.
Sir Alexander Richardson Binnie.
Henry Taylor Bovey, M.A., LL.D.
Thomas Forster Brown.
William Robert Galbraith.
George Graham.
George Henry Hill.
James Charles Inglis.
Alexander Izat, C.I.E.
Alexander Blackie William Kennedy, LL.D., F.R.S.
Sir James Kitson, Bart., M.P.
Anthony George Lyster.
John Allen McDonald.
Edward Pritchard Martin.
William Matthews.
Sir Guilford L. Molesworth, K.C.I.E.
Captain Sir Andrew Noble, K.C.B., F.R.S., late R.A.
Alexander Siemens.
Thomas Stewart.
John Isaac Thornycroft, F.R.S.
William Thwaites, M.A.
Francis William Webb.
Sir Edward Leader Williams.

[1] The Council commence their year of office on the first Tuesday in November, 1899.

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Resolved,—That the thanks of the meeting be given to the Scrutineers, and that the Ballot-Papers be destroyed.

Mr. John J. Webster responded on behalf of the Scrutineers.

Resolved,—That the thanks of the Institution be tendered to Messrs. John George Griffiths and Cuthbert Arthur Brereton, for the time and trouble bestowed by them in auditing the Accounts for the past financial year; and that they be re-appointed Auditors for the ensuing year.

Messrs. Griffiths and Brereton acknowledged the Resolution.

Resolved,—That the thanks of the Institution be tendered to the Vice-Presidents and other Members of Council, for the assistance they had rendered in promoting its objects.

Sir Douglas Fox replied on behalf of himself and his colleagues.

Resolved,—That the members present at this meeting desire, on behalf of themselves and others, to place on record their high appreciation of the services rendered to the Institution by Mr. W. H. Preece, President, during his term of office.

Mr. W. H. Preece acknowledged the Resolution.

The Meeting then ended.

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## REPORT OF THE COUNCIL, 1898–99.

THE following Report on the state of the Institution deals with the ordinary proceedings during the year now ended, and with the register and the accounts for the financial year ended on the 31st March.

The important subject of the elections into the Institution will be first alluded to. The arrangements made by the last Council to give effect to the altered conditions of election and admission have worked satisfactorily. Though necessarily involving increased labour on the part of the Council and the staff, the results have fully justified the anticipations expressed in the Report presented a year ago. Continued improvement in the answering of the examination papers is noticeable, and it is most satisfactory to find meritorious performance on the part of candidates whose grasp of scientific principles has probably been acquired in the course of earlier training.

A principal object of the Examinations Committee has been to give effect to the policy originally laid down by the Council—that the examination applying to election should deal with the scientific principles which form the basis of engineering; but, at the same time, not to restrict the requirements to the teaching of any particular school. The Associate-Membership Examinations held during the year have been passed by 107 Candidates, and those applying to Studentship by 53.

It cannot, however, be too clearly understood that the tests referred to do not in any sense either form a substitute for qualifications previously demanded by the Institution, or serve to diminish the scrutiny of the Council into the conditions of training and experience in actual engineering work, which must be satisfied by all who wish to secure election. On this account it is highly important that those who seek admittance to the Institution should understand that to be "regularly educated as a Civil Engineer," in whatever branch it be, implies training of a practical kind in the design and construction of such works as are referred to in the Charter of 1828, and, except in special cases, the serving of a regular pupilage to an engineer.

A change of some importance was made by a Special General Meeting of the members on the 20th December, when a By-law

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was enacted by which, whilst the date of election of the Council remains as before—in the month of April—the Council then elected do not commence their year of office until the beginning of the next Session, in November.

In preparing the balloting-list for the election of their successors the Council have included, among the seven new names required, two as suitable representatives resident in Canada and in Australia, in place of Mr. John Kennedy and Mr. Henry Deane; for whose three years' co-operation the Council tender the thanks of the Institution.

## The Roll.

The changes which have taken place in the Roll during the year ending the 31st March, 1899, are set forth in the accompanying Table. The elections numbered 2 Honorary Members, 28 Members, 159 Associate Members and 14 Associates; in addition to which the names of 2 Members and 9 Associate Members were restored to the register—a total of 214. By death, resignation and erasure 140 names disappeared from the list, the net increase being thus 74. On the 31st March the roll numbered 6,303, exclusive of Students, as against 6,229 on the corresponding date of last year. It may be observed that the number of elections to the class of Associate Members is 20 more than in the previous year, when the examinations were introduced; and having regard to the considerable number of present and former Students who

| | April 1, 1897, to March 31, 1898. | | | | | April 1, 1898, to March 31, 1899. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Honorary Members. | Members. | Associate Members. | Associates. | Totals. | Honorary Members. | Members. | Associate Members. | Associates. | Totals. |
| Numbers at commencement | 21 | 1,936 | 3,916 | 331 | 6,204 | 20 | 1,964 | 3,924 | 321 | 6,229 |
| Transferred to Members | .. | 54 | 54 | .. | | .. | 65 | 65 | .. | |
| Elections | .. | 34 | 139 | 9 | 195 | 2 | 28 | 159 | 14 | 214 |
| Restored to Register | .. | 2 | 11 | .. | | .. | 2 | 9 | .. | |
| Deaths | 1 | 49 | 30 | 11 | 170 | 2 | 47 | 26 | 6 | 140 |
| Resignations | .. | 8 | 19 | 8 | | .. | 5 | 22 | 2 | |
| Erased | .. | 5 | 39 | .. | 25 | .. | 3 | 26 | 1 | 74 |
| Numbers at termination | 20 | 1,964 | 3,924 | 321 | 6,229 | 20 | 2,004 | 3,953 | 326 | 6,303 |

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are already registered as having passed the Associate Membership examination, there seems ground for supposing that the most marked effect of the new system upon the roll has now been experienced.

Among the elections those of Lord Lister and of Mr. Alfred Picard as Honorary Members may be specially noticed, the total of that class being still 20, the number at which it has been maintained for many years. All the other classes of the Institution participate in the increase of strength already referred to.

On the other hand, the Council have to record with regret the unprecedented loss sustained during the year by the death of very distinguished members, among whom must be mentioned Sir Douglas Galton and Henri Schneider, Honorary Members; Harrison Hayter, Sir John Fowler and Sir Robert Rawlinson, Past-Presidents; Sir William Anderson, Vice-President, Dr. John Hopkinson, Member of Council, and Sir James Nicholas Douglass, formerly a Vice-President.

The full list of deceases is as follows:—

*Honorary Members.*—Sir Douglas Galton, K.C.B., D.C.L., F.R.S.; and Henri Schneider.

*Members.*—Sir William Anderson, K.C.B., D.C.L., F.R.S., *Vice-President;* Frederick Ashmead; William Belk; Joseph Haywood Watson Buck; Richard Butler; Francisco Javier Cisneros; Josiah Latimer Clark, F.R.S.; James Cunningham; Sir James Nicholas Douglass, F.R.S.; Charles Edward Emery; Sir John Fowler, Bart., K.C.M.G., LL.D., *Past-President;* George Greenwood; Sir Casimir Stanislaus Gzowski, K.C.M.G., *Colonel Canadian Engineers, Hon.* A.D.C.; Joseph Harrison; Harrison Hayter, *Past-President;* Jeremiah Head; William Henderson; John Hopkinson, Junior, M.A., D.Sc., F.R.S., *Member of Council;* Peter Sharp Hyslop; John Jackson; John Martin McCurrich, M.A.; Henry Daniel Martin; John Methven; Thomas Mudd; George Phillips Mulock; George Neumann; Patrick O'Meara; William Parker; Murdoch Paterson; Sir Robert Rawlinson, K.C.B., *Past-President;* Henry David Alexander Reid; William Stuart Rendel; David Rowan; Robert Thomas Scaldwell; John Richard Schram; Robert Sinclair; Thomas Sopwith; Thomas Dyne Steel; Sydney Stent; William George Strype; Edward John Tatam; Percy Thursby; George E. Waring, Junior; Joseph Westwood; William Lawrence Williams; Joseph William Wilson; and William Wilson.

*Associate Members.*—Charles Adcock; James Bell; Arthur William Bishop; Professor Samuel Cooke, M.A.; John James Cowley; James Hening Cuming; David George Davies; William James Doherty; Richard Oliver Gardner Drummond; Herbert Evington; John Francis Foster; Henry Masterton; William Michell; George Napier; Henry Adair Orr; Alfred Lindley Peace; James Wallace Peggs; Thomas Cheveley Rayner; Hudson Reah; William Henry Scriven; James Folliott Stokes; Lucas Thomasson; John White; Leonard Wigan; Francis Samuel Wilde; and Hugh Williams.

*Associates.*—Samuel Bayliss; Arthur Edward Guest; John Barber Lindsell, *Lieut.-Colonel* R.E. *ret.;* John Rawlins; Samuel Swarbrick; and George Frederick White.

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The following resignations have been accepted:—

*Members.*—Beresford Anderson; James George Green; Herbert Dent Johnston; Stair Agnew Stewart; and James Tait.

*Associate Members.*—William Anderson; Randal James Callander; Frederick Richard Clapham; Thomas Colson; John Edward Compton-Bracebridge; John Poole Davis; Edmond Power Dowley; Francis William Fox; Robert William Lyons Hawkins; Gilbert Reginald Henderson; William Frederick Howard; Charles Cornwallis Burton Knapp; Charles Erskine May; Ernest Anthony Nardin; Henry Hollinworth Parkinson; Giles Henry Powell; Charles Lawrence Pemberton Robinson; Arthur Stannard; William Brounger Taylor; Louis Edward Tylor; James Wallace; and Oswald Vavasour Yates.

*Associates.*—Sir Henry Edward McCallum, *Major* R.E., K.C.M.G.; and Henry Wyndham Sich.

## Admission of Students.

The accompanying Table gives the changes which have taken place in the Student class during the year under review. The admissions amounted to 220, and 1 was restored to the list, while 204 names were removed, by reaching the age-limit, by election to the class of Associate Members, by resignation, death and erasure. The total on the 31st March was 964, as against 947 at the corresponding date of last year. The continued increase in the number of admissions affords evidence of the value attached to Studentship, in the face of the personal effort required to attain it. The actual number of Students elected Associate Members during the year—31—does not convey a proper idea of the contribution of this class to the strength of the Institution, for it appears that as many as 56 of the Associate Members elected were or had previously been Students.

### Students.

| 1897–98. | | | 1898–99. | | |
|---|---|---|---|---|---|
| April 1, 1897 | | 886 | April 1, 1898 | | 947 |
| Admitted during the year | 201 | | Admitted during the year | 220 | |
| Restored to List | 1 | | Restored to List | 1 | |
| | 202 | | | 221 | |
| Elected Associate Members | 19 | | Elected Associate Members | 31 | |
| Elected Associate | .. | | Elected Associate | 1 | |
| Resigned | 16 | | Resigned | 17 | |
| Deceased | 1 | | Deceased | 1 | |
| Erased and removed over age | 105 | | Erased | 1 | |
| | | | Removed—over age | 153 | |
| | 141 | | | 204 | |
| | 61 | | | 17 | |
| March 31, 1898 | | 947 | March 31, 1899 | | 964 |

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## Finance.

The Statement of Accounts, examined and signed by the Auditors, will be found at p. 254.

The receipts during the year were as follows: Income, £22,258 4*s.* 2*d.*, consisting of subscriptions £18,794 0*s.* 9*d.*, dividends £1,667 10*s.*, rents £955 4*s.*, and miscellaneous items £841 9*s.* 5*d.*; on Capital account £2,213 8*s.*, representing admission fees and life compositions; and Trust Funds £561 13*s.* 4*d.*, of which £93 14*s.* 8*d.*, subscribed to found the "James Forrest" Medal, was invested in the purchase of £52 South Eastern Railway 5 per Cent. Debenture Stock. The Expenditure amounted to:—Income account £20,688 13*s.* 8*d.*, including £1,117 17*s.* 6*d.* for rates and taxes and £8,158 0*s.* 3*d.* for publications; and Trust Funds account £489 2*s.* 10*d.*

During the year the Midland Railway 3 per cent. Debenture Stock has been converted into 2½ per cent. Stock, the amount held by the Institution being increased from £8,000 to £9,600. The investments on Institution account now aggregate, therefore, £53,600 (nominal value), purchased for £54,884 5*s.* 8*d.*, and the various Trust Funds amount to £17,144 0*s.* 9*d.*

## Session and Meetings.

Twenty-two ordinary meetings were held during the Session, at which fourteen Papers were read and discussed, the address of the President and the presentation of awards, as usual occupying the opening meeting.

A general consideration of the subjects brought forward indicates that Papers touching questions of mining and metallurgy so largely preponderated as to render the Session noteworthy in regard to that branch of engineering. It has been before explained in these Reports that the Council do not seek to concentrate the contribution of information into any particular channel. The occurrence of so many Papers dealing with the extraction of metals, or their subsequent treatment and behaviour, affords an indication of the trend of professional activity at the present moment, stimulated, doubtless, by the competition of other countries in domains in which British engineers formerly maintained their pre-eminence with comparatively little effort.

Dealing *seriatim* with the Papers read and discussed, Sir William Roberts-Austen, in "The Extraction of Nickel from its Ores by the Mond process," gave an exposition of an entirely novel process

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in metallurgy. Mr. Esson's account of "Electrical Transmission of Power in Mining" referred to engineering operations, by the aid of which the extraction of metals may be rendered commercially successful in situations where the ores are not rich enough to allow of working by older methods. Mr. Kay's memoir on "The Effect of Subsidence due to Coal-Workings upon Bridges and other Structures," while directly affecting works of construction, involved some important economical considerations in reference to the methods of working coal in certain situations.

The last communication read before the Christmas recess, the consideration of which occupied three evenings, was that by Mr. Francis Fox on "The Ventilation of Tunnels and Buildings." It raised the important question of the ventilation of railway tunnels by natural or artificial means, and gave rise to an animated discussion. The first meeting of the new year was occupied in considering a Paper by Mr. J. H. Dales on "High-Speed Engines." Next followed "The Effect of Wear upon Steel Rails," by Mr. W. G. Kirkaldy. A contribution by Sir William Roberts-Austen directing attention to the "Photo-micrography of Steel Rails," formed a valuable addendum to Mr. Kirkaldy's Paper. The next Paper read was one in which "The Waterworks of the Madras Presidency" were described and compared by Mr. J. A. Jones. This was of a type well suited for discussion, as setting forth the conditions governing the adoption in various cases of different plans to secure a pure and sufficient supply of water to populous towns in India. This Paper was followed by "The Lake Superior Iron-Ore Mines, and their Influence upon the Production of Iron and Steel," by Messrs. Jeremiah and A. P. Head. The illness and death of the first-named Author very shortly after this Paper was under consideration elicited an expression of widespread regret among the members. In "Improvements in Dioptric Apparatus for Lighthouses," Messrs. W. T. Douglass and J. A. Purves described the system of "*Feux Éclairs*" "lightning flash" lights recently introduced into the French lighthouse service. This development is an outcome of the system of group-flashing lights devised in 1875 by our late Member of Council Dr. John Hopkinson. Mr. J. T. Milton's review of "Water-Tube Boilers for Marine Engines," and the account of "Recent Trials of the Machinery of Warships," by Sir John Durston and Mr. H. J. Oram, being divisions of one subject, were as such discussed together. Following these, another metallurgical Paper, "Alloys of Iron and Nickel," by Mr. R. A. Hadfield, formed a valuable addition to the previous contribution of the Author to the Institution, and

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carried somewhat further the problem of the effect of varying proportions of foreign substances on the properties of steel. The last Paper of the Session, by Mr. J. M. Dobson, gave an account of the "Buenos Ayres Harbour Works," recording the successful completion of a work of the first importance after years of discouraging delay and adverse political influences.

In respect of these Papers, awards have been made to Messrs. R. A. Hadfield, J. T. Milton, Sir A. J. Durston and H. J. Oram, Francis Fox, Sir Wm. C. Roberts-Austen, J. M. Dobson, W. G. Kirkaldy, and A. P. Head.

The series of Papers selected for publication without discussion has been no less varied and instructive than usual. The awards for those published in Section II. will in accordance with custom be announced in the autumn.

It may be interesting to remark that the number of original communications published by the Institution has averaged fifty-five annually during the past five years. By such records of investigations and experience the members at once contribute to the immediate benefit of their fellows and promote in the best possible way the objects for which the Society was formed.

## The "James Forrest" Lecture.

Magnetism, in its relation to engineering, formed the subject of the seventh "James Forrest" lecture, which was delivered at a special meeting on the 20th April by Professor J. A. Ewing, M. Inst. C.E. For this lecture, which was highly appreciated by the audience, see *post*, p. 289.

## Students' Meetings.

The customary series of Students' meetings and visits to works have been held during the Session, though in point of both attendance and Papers submitted at the meetings held in London, the Council regret to notice a failure to maintain the improvement of recent years. It is perhaps impossible without a personal touch which is precluded by the very extent of the Student Class, for the Council to bring completely home to those who are entering the profession the advantages to be gained by familiarity with the art of formally stating and debating engineering problems; and they must therefore rely to a large extent upon individual members to influence Students towards availing themselves of the opportunities for self-improvement afforded by the Institution.

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With a view to augment the educational advantages placed within the reach of Students, the Council have obtained this Session the co-operation of Dr. Barr, M. Inst. C.E., Professor of Civil Engineering and Mechanics in the University of Glasgow, who most kindly delivered, on the 11th January, a special Address to the Students, on "The Application of the Science of Mechanics to Engineering Practice." This lecture, which is well worthy of perusal by all who are interested in engineering education, was issued with Part II of the Proceedings of the Session.

## General Business.

Among matters which in the ordinary routine have engaged attention during the year may be mentioned the development of plans for the erection of public offices in proximity to the Institution. Plans have been submitted to Parliament which, if carried out in their entirety, would affect the Institution premises; but no steps have yet been taken to interfere in any way with the rights secured to the Institution by the Public Buildings (Westminster) Act 1897.

The premises have been enriched during the year by gifts of marble busts of James Walker, Past-President, and Sir Henry Bessemer, Honorary Member, the former by the grand-children, the latter by the executors. With great pleasure the Council also record that a portrait of Mr. Edward Woods, Past-President, has been presented.

In response to a request from the Royal Society the Council have nominated Mr. W. H. Preece, President, and Sir John Wolfe Barry, Past-President, to represent the Institution on the General Board of the National Physical Laboratory.

The usual conversazione was held in May, 1898, and was attended by 2,500 persons. The Council have made the preliminary arrangements for holding the second Engineering Conference next June, and do not doubt that they will receive the support of the members in this step, which is admitted on all hands to be well calculated to promote the unity of the Institution.

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## ABSTRACT *of* RECEIPTS *and* EXPENDITURE

### RECEIPTS.

| *Dr.* | £. | s. | d. | £. | s. | d. |
|---|---|---|---|---|---|---|
| To Balance, 1 April, 1898, viz.:— | | | | | | |
| Cash in the hands of the Treasurer . . . | 3,171 | 6 | 7 | | | |
| „ „ „ Secretary . . . | 1 | 7 | 0 | | | |
| | | | | 3,172 | 13 | 7 |

#### INCOME.

| | £. | s. | d. | £. | s. | d. |
|---|---|---|---|---|---|---|
| — Subscriptions received:— | | | | | | |
| Arrears, prior to 1 January, 1898 | 462 | 12 | 6 | | | |
| For the year 1898 . . . . | 4,470 | 19 | 9 | | | |
| For the year 1899 . . . . | 13,854 | 13 | 0 | | | |
| Advance . . . . . | 5 | 15 | 6 | | | |
| | | | | 18,794 | 0 | 9 |
| — Minutes of Proceedings:—Repayment for Binding, &c. . . . . | | | | 458 | 15 | 5 |
| — Library Fund . . . . . | | | | 75 | 13 | 0 |
| — Dividends: 1 year on | | | | | | |

*Institution Dividends.*

| £ | | £. | s. | d. | £. | s. | d. |
|---|---|---|---|---|---|---|---|
| 2,000 | 2¾% Consols . . . | 53 | 3 | 4 | | | |
| 6,000 | Metropolitan 3½% Stock | 203 | 0 | 0 | | | |
| 6,000 | Great Eastern Railway 4% Debenture Stock. | 232 | 0 | 0 | | | |
| 8,000 | Great Northern Ry. 3% Debenture Stock . . | 232 | 0 | 0 | | | |
| 8,000 | Great Western Ry. 4% Debenture Stock . . | 309 | 6 | 8 | | | |
| 8,000 | Lancs. & Yorks. Ry. 3% Debenture Stock . . | 232 | 0 | 0 | | | |
| 6,000 | London & N.W. Ry. 3% Debenture Stock . . | 174 | 0 | 0 | | | |
| 9,600 | Midland Ry. 2½% Debenture Stock . . | 232 | 0 | 0 | | | |
| £53,600 | Nominal or par value. | | | | 1,667 | 10 | |
| — Rents—No. 27 Great George St. . . . . | | | | | 955 | 4 | 0 |
| — Miscellaneous . . . . . | | | | | 2 | 11 | 0 |
| — Examination Fees . . . . . | | | | | 304 | 10 | 0 |
| | | | | | | 22,258 | 4 | 2 |
| Carried forward . . . . . | | | | | | £25,430 | 17 | 9 |

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*from the* 1ST APRIL, 1898, *to the* 31ST MARCH, 1899.

## EXPENDITURE.

*Cr.* GENERAL EXPENDITURE.

| | £. s. d. | £. s. d. | £. s. d. |
|---|---|---|---|
| By House and Establishment Charges:— | | | |
| Repairs:— General | 148 3 3 | | |
| No. 27 Gt. George St. | 16 11 0 | | |
| | | 164 14 3 | |
| Rent of No. 27 Great George Street | | 600 0 0 | |
| Rates and Taxes:—The Institution | 943 6 8 | | |
| No. 27 Gt. George St. | 174 10 10 | | |
| | | 1,117 17 6 | |
| Insurance:—The Institution | 80 13 9 | | |
| No. 27 Gt. George St. | 4 12 0 | | |
| | | 85 5 9 | |
| Fixtures and Furniture | | 446 13 5 | |
| Lighting, Warming and Ventilating:— | | | |
| The Institution | 260 2 3 | | |
| No. 27 Gt. George St. | 8 9 10 | | |
| | | 268 12 1 | |
| Charges for Water (including lifts), Rent of Telephone, &c. | 100 3 0 | | |
| Charges for Water, No. 27 Gt. George St. | 18 6 0 | | |
| | | 118 9 0 | |
| Refreshments at Meetings | | 89 17 11 | |
| Assistance at Meetings | | 19 7 0 | |
| Students' Meetings (including refreshments), Donation to Annual Dinner, and Visits | | 264 11 5 | |
| Household Expenses | | 368 18 2 | |
| | | | 3,544 6 6 |
| — Postages, Telegrams, and Parcels | | 383 0 11 | |
| — Stationery and Printing | | 673 14 8 | |
| — Watt Medals | | 4 15 0 | |
| — Stephenson Medals | | 7 2 6 | |
| — James Forrest Medals | | 7 17 6 | |
| — Diplomas | | 30 19 8 | |
| — Annual Dinner (balance of 1898 and part 1899) | | 308 1 7 | |
| — Conversazione | | 1,172 2 11 | |
| — Conference (part 1899) | | 7 7 3 | |
| | | | 2,595 2 0 |
| — Salaries | | 2,300 0 0 | |
| — Clerks, Messengers, and Housekeeper | | 1,428 6 8 | |
| — Retiring Allowances and Donations | | 1,312 0 0 | |
| | | | 5,040 6 8 |
| — Library:—Books and Periodicals | | 229 8 11 | |
| Binding | | 153 15 9 | |
| | | | 383 4 8 |
| — Publications:— | | | |
| "Minutes of Proceedings," Vols. cxxxii., cxxxiii., cxxxiv. and cxxxv. | | 7,746 10 8 | |
| Charters, By-Laws, and Lists of Members | | 411 9 7 | |
| | | | 8,158 0 3 |
| Carried forward | | | £19,721 0 1 |

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## ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

*Dr.*

| | £. | s. | d. |
|---|---|---|---|
| Brought forward . . . . . | 25,430 | 17 | 9 |

CAPITAL.

| | £. | s. | d. | | | |
|---|---|---|---|---|---|---|
| To Admission-Fees . . . . . | 2,097 | 18 | 0 | | | |
| — Life-Compositions . . . . . | 115 | 10 | 0 | | | |
| | | | | 2,213 | 8 | 0 |

| | | | |
|---|---|---|---|
| Carried forward . . | £27,644 | 5 | 9 |

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*from the* 1ST APRIL, 1898, *to the* 31ST MARCH, 1899.

EXPENDITURE—*continued.*

| *Cr.* | | | £. | s. | d. |
|---|---|---|---|---|---|
| Brought forward | | | 19,721 | 0 | 1 |
| By Legal Expenses | 35 5 2 | | | | |
| Memorial to Mr. Akers Douglas | 11 9 8 | | | | |
| — Professional Auditor's Fee | 36 15 0 | | | | |
| Expenses of the Paris and Brussels Delegates | 64 6 8 | | | | |
| | | | 147 | 16 | 6 |
| — Examinations | 630 8 11 | | | | |
| — Donation to Westminster Hospital | 10 10 0 | | | | |
| — Donation to Humphry Davy Memorial | 52 10 0 | | | | |
| | | | 693 | 8 | 11 |
| Charges *re* negotiations for purchase of No. 27 Gt. George St. (including Architect's plans) | | | 126 | 8 | 2 |
| | | | 20,688 | 13 | 8 |

Carried forward . . £20,688 13 8



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## ABSTRACT *of* RECEIPTS *and* EXPENDITURE

### RECEIPTS—*continued.*

*Dr.*

| | £. | s. | d. |
|---|---|---|---|
| Brought forward | 27,644 | 5 | 9 |

**Trust Funds.**

*Telford Fund.*

To Dividends:—1 year on

| £. | s. | d. | | £. | s. | d. | £. | s. | d. |
|---|---|---|---|---|---|---|---|---|---|
| 5,439 | 11 | 0 | 2¾% Consols | 144 | 12 | 4 | | | |
| 3,299 | 2 | 0 | Ditto (Unexpended Dividends) | 87 | 14 | 0 | | | |
| £8,738 | 13 | 0 | | | | | 232 | 6 | 4 |

*Manby Donation.*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| £250 | 0 | 0 | Great Eastern Ry. 4% Irredeemable Guaranteed Stock | | | | 9 | 13 | 4 |

*Miller Fund.*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3,125 | 0 | 0 | 2¾% Consols | 83 | 1 | 4 | | | |
| 2,004 | 17 | 5 | Ditto (Unexpended Dividends) | 53 | 6 | 0 | | | |
| £5,129 | 17 | 5 | | | | | 136 | 7 | 4 |

*Howard Bequest.*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| £551 | 14 | 6 | 2¾% Consols | | | | 14 | 13 | 4 |

*Trevithick Memorial.*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| £103 | 0 | 0 | 2¾% Consols | | | | 2 | 14 | 8 |

*Crampton Bequest.*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| £512 | 15 | 11 | 2¾% Consols | | | | 13 | 12 | 8 |

*James Forrest Lecture and Medal Fund.*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Balance subscribed for a Testimonial and handed to the Institution to form a Medal Fund | 93 | 14 | 8 | | | |
| 320 | 0 | 0 | South-Eastern Ry. 5% Debenture Stock | 15 | 9 | 4 | | | |
| 52 | 0 | 0 | Ditto (New Purchase) | 0 | 0 | 0 | | | |
| £372 | 0 | 0 | | | | | 109 | 4 | 0 |

*Palmer Scholarship.*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1,381 | 1 | 6 | Metropolitan 3% Stock | 40 | 1 | 0 | | | |
| 104 | 18 | 5 | Ditto (Unexpended Dividends) | 3 | 0 | 8 | | | |
| £1,485 | 19 | 11 | | | | | 43 | 1 | 8 |
| | | | | | | | | | 561 | 13 | 4 |
| | | | | | | | | £28,205 | 19 | 1 |

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*from the* 1ST APRIL, 1898, *to the* 31ST MARCH, 1899.

EXPENDITURE—*continued.*

| *Cr.* | | | | £. | s. | d. |
|---|---|---|---|---|---|---|
| | Brought forward | | | 20,688 | 13 | 8 |
| | TRUST FUNDS. | | | | | |
| | | £. | s. d. | | | |
| By | Telford Premiums | 215 | 10 2 | | | |
| | Less excess of awards refunded | 14 | 14 8 | | | |
| | | 200 | 15 6 | | | |
| — | Telford Medals | 6 | 0 0 | £. | s. | d. |
| | | | | 206 | 15 | 6 |
| — | Miller Prizes | | | 128 | 15 | 6 |
| — | Crampton Prizes | 20 | 14 0 | | | |
| | Less excess of award refunded | 3 | 6 6 | | | |
| | | | | 17 | 7 | 6 |
| — | "James Forrest" Lecture and Medal Fund— Purchase of £52 South-Eastern Railway 5% Debenture Stock | | | 94 | 14 | 0 |
| — | Palmer Scholarship— 1 year's dividend to Scholar | | | 41 | 10 | 4 |
| | | | | | 489 | 2 10 |
| | | | | | 21,177 | 16 6 |
| — | Balance, 31 March, 1899, viz.:— | | | | | |
| | On Deposit | | | 5,000 | 0 0 | |
| | Cash in the hands of the Treasurer | | | 2,016 | 2 11 | |
| | ,, ,, Secretary | | | 11 | 19 8 | |
| | | | | | 7,028 | 2 7 |
| | | | | | £28,205 | 19 1 |

J. H. T. TUDSBERY, *Secretary.*
10 *April*, 1899.

Examined with the Books and Securities and found correct.

(Signed) JOHN G. GRIFFITHS, F.C.A.
CUTHBERT A. BRERETON. } *Auditors.*



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## STATEMENT OF INVESTMENTS HELD 31 MARCH, 1899.

### Institution Investments.

| £ | | £. s. d. | £. s. d. |
|---|---|---|---|
| 2,000 | 2½% Consols . . . . . | Cost 1,967 19 1 | |
| 6,000 | Metropolitan 3½% Stock . . . | „ 6,517 15 0 | |
| 6,000 | Great Eastern Railway 4% Debenture Stock . . . . . | „ 7,749 18 3 | |
| 8,000 | Great Northern Railway 3% Debenture Stock . . . . . | „ 7,642 16 4 | |
| 8,000 | Great Western Railway 4% Debenture Stock . . . . . | „ 10,547 5 0 | |
| 8,000 | Lancashire and Yorkshire Railway 3% Debenture Stock . . . . | „ 7,452 14 8 | |
| 6,000 | London and North Western Railway 3% Debenture Stock . . | „ 5,544 18 5 | |
| 9,600 | Midland Railway 2½% Debenture Stock . . . . . | „ 7,460 18 11 | |
| 53,600 | | | 54,884 5 8 |

Freehold of Institution Premises and New Building:—

Cost, including buildings now removed . £124,379 10 0

Valued by Messrs. Edward Ryde and Sons on the 14th August, 1896, as land and buildings, apart from value to the Institution . . . . . .. 88,000 0 0

Note.—No value has yet been attached, for the purpose of this statement, to the Books, Furniture, Fittings, Pictures, &c., in the Institution Building nor to the lease of No. 27 Great George Street. 142,884 5 8

### Trust Funds Investments.

| £. s. d. | | | £. s. d. |
|---|---|---|---|
| | | *Telford Fund.* | |
| 1,945 19 0 | 2½% Consols | —Acquired with a bequest of . . | 2,000 0 0 |
| 3,479 12 9 | do. | Converted from Government Stocks bequeathed . . . . . | Bequest. |
| 13 19 3 | do. | Purchased with bonus on conversion cost . . . . . | 13 11 3 |
| 5,439 11 0 | | | |
| 3,299 2 0 | do. | Purchased with unexpended dividends . . . . . | 3,034 18 1 |
| 8,738 13 0 | | | |
| | | *Manby Donation.* | |
| 250 0 0 | Great Eastern Railway 4% Irredeemable Guaranteed Stock . . . . . | | Donation. |
| | | *Miller Fund.* | |
| 3,125 0 0 | 2¾% Consols | —Acquired with a bequest of . . | 3,000 0 0 |
| 2,004 17 5 | do. | Purchased with unexpended dividends . . . . . | 1,850 2 4 |
| 7 5 | | | |

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TRUST FUNDS INVESTMENTS—*continued.*

| £. | s. | d. | | £. | s. | d. |
|---|---|---|---|---|---|---|
| | | | *Howard Bequest.* | | | |
| 551 | 14 | 6 | 2½% Consols—Acquired with a bequest of . . | 500 | 0 | 0 |
| | | | *Trevithick Memorial.* | | | |
| 103 | 0 | 0 | 2½% Consols—Acquired with a presentation of . | 100 | 0 | 9 |
| | | | *Crampton Bequest.* | | | |
| 512 | 15 | 11 | 2½% Consols—Acquired with a bequest of . . | 500 | 0 | 0 |
| | | | *James Forrest Lecture and Medal Fund.* | | | |
| 320 | 0 | 0 | South Eastern Railway 5% Debenture Stock acquired with a subscription of . . . . . | 510 | 0 | 0 |
| 52 | 0 | 0 | Ditto acquired with a subscription of £93 14*s.* 8*d.* and 19*s.* 4*d.* cash . . . . . | 94 | 14 | 0 |
| 372 | 0 | 0 | | | | |
| | | | *Palmer Scholarship.* | | | |
| 1,381 | 1 | 6 | Metropolitan 3% Stock bequeathed . . . . | Bequest. | | |
| 104 | 18 | 5 | Ditto purchased with unexpended dividends. . | 122 | 6 | 3 |
| 1,485 | 19 | 11 | | | | |

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## MEDALS AND PREMIUMS AWARDED FOR THE SESSION 1897–98, AND PRESENTED ON THE 1ST NOVEMBER, 1898.

### FOR PAPERS READ AND DISCUSSED AT THE ORDINARY MEETINGS.

1. A Telford Medal and a Telford Premium to Arthur Henry Preece, Assoc. M. Inst. C.E., for his Paper on "The Electricity Supply of London."
2. Watt Medals and Telford Premiums to Hugh Longbourne Callendar, M.A., F.R.S., and to John Thomas Nicolson, B.Sc., for their Paper on "The Law of Condensation of Steam."
3. George Stephenson Medals and Telford Premiums to Whately Eliot and to William Oliver Evelyn Meade-King, MM. Inst. C.E., for their descriptions of "The Manchester Ship-Canal."
4. A Crampton Prize to Edward William Anderson, Assoc. M. Inst. C.E., for his Paper on "The Machinery used in the Manufacture of Cordite."
5. A Telford Premium to Llewelyn Birchall Atkinson,[1] Assoc. M. Inst. C.E., for his Paper on "The Theory, Design and Working of Alternate-Current Motors."
6. A Telford Premium to Henry Fowler, Assoc. M. Inst. C.E., for his Paper on "Calcium Carbide and Acetylene."
7. A Telford Premium to William Lumisden Strange, Assoc. M. Inst. C.E., for his account of "Reservoirs with High Earthen Dams in Western India."

### FOR PAPERS PRINTED IN SECTION II OF THE PROCEEDINGS FOR THE SESSION 1897–98.

1. A George Stephenson Medal and a Telford Premium to William Prime Marshall, M. Inst. C.E., for his account of the "Evolution of the Locomotive Engine."
2. A Telford Medal and a Telford Premium to Henry Charles Stanley, M. Inst. C.E., for his description of the "Re-erection of the Albert Bridge, Brisbane."
3. A Telford Premium to David William Brunton, M. Inst. C.E., for his Paper on "The Cowenhoven Adit-Level."

[1] Has previously received a Telford Medal and Premium.

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4. A Telford Premium to Francis John Waring, C.M.G., M. Inst. C.E., for his description of "The Haputale and Bandarawela Extension of the Ceylon Government Railway."
5. A Telford Premium to Henry Vine Champion, Assoc. M. Inst. C.E., for his Paper on "Section No. 1, North Yarra Main Sewer."
6. A Telford Premium to David Butler Butler, Assoc. M. Inst. C.E., for his Paper on "The Finer Grinding of Portland Cement, and the Comparative Value of the Coarser Particles."
7. A Telford Premium to Wilfrid Airy,[1] B.A., M. Inst. C.E., for his Paper on "The Pressure of Grain."
8. A Telford Premium to Ella Mary Bryant, B.Sc., for her Paper on "The Thermal Condition of Iron, Steel and Copper when acting as Boiler-Plates."

FOR PAPERS READ BEFORE MEETINGS OF STUDENTS.

1. The "James Forrest" Medal and a Miller Prize to William Lowe Brown, M.Sc., Stud. Inst. C.E., for his Paper "Elasticity of Portland Cement," read at the Institution.

and Miller Prizes to the following, for Papers read at the Institution:—

2. Archer Dave Keigwin, Stud. Inst. C.E., for his description of "The Elastic Properties of Steel Wire."
3. Harold Williams, Stud. Inst. C.E., for his Paper on "Condensing Apparatus."
4. Charles Ernest Wolff, B.Sc., Stud. Inst. C.E., for "The Problem of Train Resistance."
5. John Turner Morris, Stud. Inst. C.E., for "The Protection of Electric Power Transmissions from Lightning."
6. Henry Charles Adams, Stud. Inst. C.E., for "The Drainage of Cottage Property."
7. Hermann Oscar Eurich, Stud. Inst. C.E., for his Paper on "Internal Governor Friction."

and for Papers read before Local Associations of Students:—

8. Bertram Keith Adams, Stud. Inst. C.E. (Manchester), for his Paper "The Crossing of the Manchester, Bolton and Bury Canal by the Intercepting Sewer of the Bury Corporation."

[1] Has previously received Telford and Manby Premiums.

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9. Philip Francis Story, Stud. Inst. C.E. (Manchester), for hi Paper on "The Destruction of Towns Refuse and th Utilization of Power and of By-products."
10. Alfred Brown Ernest Blackburn, Stud. Inst. C.E. (Birmin ham), for his Paper on "Engineering Education from Student's Standpoint."
11. David Ernest Lloyd-Davies, Stud. Inst. C.E. (Birmingham for his description of "Modern Methods of Sewage Di posal."
12. Thomas Carter,[1] Stud. Inst. C.E. (Newcastle-on-Tyne), for h Paper "Units of Measurement; with special reference t the Metric System."
13. Wilfred Hall, B.A., Stud. Inst. C.E. (Newcastle-on-Tyne) f his description of "The Plant used in the Construction the Central London Railway."

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[1] Has previously received a Miller Prize.

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# SUBJECTS FOR PAPERS, PREMIUMS, AND INSTRUCTIONS FOR PREPARING ORIGINAL COMMUNICATIONS.

SESSION 1899–1900.

THE COUNCIL of The Institution of Civil Engineers invite Original Communications on the Subjects included in the following List, as well as on other questions of professional interest. This list is to be taken merely as suggestive, and not in any sense as exhaustive. For approved Papers the Council have the power to award Premiums, arising out of Funds bequeathed for the purpose, the particulars of which are as under:—

1. The TELFORD FUND, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces a gross amount of £235 annually.

2. The MANBY DONATION, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The MILLER FUND, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises nearly £140 per annum. Out of this Fund the Council has established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and is prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years. No Paper will be received from a Student in competition for the Miller Scholarship and the Miller Prizes when he has become qualified by age, viz. twenty-five years, for election into the Corporation.

4. The HOWARD BEQUEST, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution. The annual income amounts to nearly £15. It has been arranged to award this prize every five years commencing from 1877. The next award will be made in 1902.

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5. The CRAMPTON BEQUEST of £500, free of legacy duty, has been invested in the purchase of £512 15*s.* 11*d.* 2¾ per cent. consols, and the income arising therefrom is now £13 14*s.* This trust is for the purpose of founding "a Prize to be called the 'Crampton Prize,' so that the interest of the said legacy shall be annually expended in a medal or books or otherwise . . . . for presentation to the Author of the best Paper on 'The Construction, Ventilation and Working of Tunnels of Considerable Length,' or failing that then on any other subject that may be selected."

6. The balance of the TREVITHICK MEMORIAL FUND, amounting to £100 0*s.* 9*d.*, has been accepted for a periodical Premium to be called after Richard Trevithick. This sum has been placed in £103 2¾ per cent. consols, upon which the interest is £2 15*s.* a year.

7. The JAMES FORREST MEDAL, founded in 1897, is endowed with the balance of a sum of money given by those who had served on the Council towards a presentation to Mr. Forrest on his retirement from the Secretaryship. The medal is awarded annually to a Student of the Institution who contributes the best Paper received from that class.

8. The JAMES PRESCOTT JOULE MEDAL is placed by the Trustees of the Endowment Fund at the disposal of the Council, in every third year, for award to a Student of The Institution, for the best Paper presented on an engineering subject, "preference being given to a Paper dealing with the transformation of energy." The medal will be at disposal next in 1900.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the premiums no distinction will be made between essays received from members of the Institution or strangers, whether Natives or Foreigners, except in the cases of the Miller and the Howard bequests and the James Forrest and James Prescott Joule medals, which are limited by the donors.

### LIST OF SUBJECTS.

1. The most economical Methods of Handling large masses of Excavation, as exemplified in modern canal construction.
2. The Measures necessary for the improvement of Canal Navigations.
3. The Methods adopted in carrying out large Dock and Harbour Works, with descriptions of the Plant employed.

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4. The Appliances for Dredging and for Removing Rock in deep water, with details of the time occupied in the various operations.
5. The Application of Compressed Air, steam and hydraulic power to Rock-drills.
6. The Design and Construction of Railway Carriages, having reference to (*a*) lavatory accommodation; (*b*) provision for refreshments; and (*c*) sleeping arrangements.
7. Standard and Metre-gauge rolling-stock on Indian railways.
8. The Modern Methods of Pumping compared in regard to cost and efficiency.
9. The Use of Steel in the Construction of large Tanks.
10. The Employment of Storage-Reservoirs in Irrigation and in the Conservation of Rivers.
11. The Purification of Sewage by biological and chemical agencies.
12. The Use of Ash-bin Refuse in towns for the production of steam.
13. The Purification of large quantities of Water after its use in Manufactories.
14. The Production and Enrichment of Water Gas.
15. The methods of conveying and of using Natural Gas.
16. The Construction and Use of Water-Tube Boilers.
17. The Utilization of Heat (*a*) generated in the compression of air and other gases; (*b*) carried away by steam-engine condenser-water; and (*c*) contained in boiler-furnace flue-gases.
18. The Methods of Condensing Steam by the use of moderate quantities of water.
19. The Methods of removing Moisture from Steam, and of reducing losses by radiation from steam-pipes.
20. The Theory and Development of the Compound Steam-Turbine.
21. The Application of Steam- Oil- and Gas-Engines to tractive purposes on common roads and on tramways.
22. The Design and Construction of large Turbines.
23. The Forms of Turbine most suitable for small Falls.
24. The Methods of Testing the Lubricating Values of Oils, Greases, etc.
25. The Comparative Merits of Blast- and Reverberatory Furnaces.
26. The Manufacture and Use of Steel for Electro-magnetic Purposes.
27. The Manufacture of Steel for Structural Purposes.
28. The use of Cast-Iron, Steel, and Wooden Sleepers; their suitability for various kinds of ballast, and the effect of salts contained in the ballast, and of sea air upon them.

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29. The Use of Steel of great tensile strength in Ships and other structures.
30. Recent improvements in the Manufacture of Armour-Plates.
31. The Strength of Steel Shafts, Tubes and Cylinders.
32. The Sinking of Shafts through various kinds of strata, including sand, and with the methods of dealing with large feeders of water.
33. Boring-Machinery suitable for different kinds of rock, having regard to rapidity of progress and reliability in the various strata traversed.
34. Mechanical Appliances for Coal-getting.
35. The use of Explosives underground in different kinds of strata, as well as under water and in connection with dusty and fiery Mines.
36. The Mining of Thick and of Thin Seams of Coal, under different conditions of working with strong and weak roofs and floors.
37. The Underground Arrangements in Collieries.
38. The Influence of Coal-dust in contributing to Colliery Explosions.
39. The Use of Electric Energy in working Mines.
40. The Drainage of Mines by Pumping and by Tunnelling.
41. The Extraction of Metals from their Ores by electrolytic processes.
42. Argentiferous Lead Smelting in Water-jacketed blast-furnaces
43. The Methods of Gold-mining in California and other Countries.
44. The Occurrence, Production and Uses of (*a*) Asbestos, (*b*) Arsenic, and (*c*) Mercury.
45. The Metallurgy of Chromium, Molybdenum and other rare metals, and their use in the Manufacture of Steel.
46. The design, construction, erection and working of Modern Stamp Mills.
47. The Machines for Raising Mineral Tailings, as lifting-wheels, pumps, dredgers, etc.
48. The most suitable Steam-power Equipments for Electric-light stations.
49. The Utilization of Electric-Lighting Plant during hours of small demand.
50. The Utilization of Electric Energy in the form of heat.
51. The Regulation of Electric pressure in large lighting circuits as carried out at the engine, the dynamo, or the exciter.
52. The Use of Electric Motors for driving machines in textile factories and in engineering workshops.

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53. The first cost, facility and economy of operation of Electric Traction on Railways with heavy trains.
54. The application of Electricity to Traction on Roads and Tramways.
55. The Electrolytic Action of Return Currents in Electrical Tramways on gas- and water-mains, and the best means of providing against Electrical Disturbances.
56. The most suitable Alloys for the working parts of Pumps for lifting corrosive liquids from mines, etc.
57. The Methods of Preventing or Arresting the Corrosion of Hydraulic Rams of large diameter.
58. The Use and Durability of Cast-iron Pipes and other structures in contact with various soils.
59. The Durability of Wrought Iron and Steel Structures exposed to fresh, salt and brackish water.
60. The Use of the Die-press in workshop operations.
61. The Appliances used in the Manufacture of Smokeless Powder.
62. The different systems of Refrigeration, and of appliances for the storage and Preservation of Food Produce.
63. Brine-pumping and the Manufacture of Common Salt.
64. The present Limits of Speed at Sea.
65. The most recent types of (*a*) Passenger and Mail Steamers; (*b*) Cargo-Steamers.
66. The Relative Advantages of Single-Screws, of Twin-Screws, and of Triple-Screws in large vessels.
67. The Use of Electrical Machinery for lighting and the transmission of power in warships and in the mercantile marine.
68. The best position for Torpedo-Discharging Tubes on large vessels, with a fixed direction, or trainable.
69. The Progress of Telegraphy and Telephony at home and abroad.

### Instructions for Preparing Original Communications.

In writing these Essays the use of the first person should be avoided. They should be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract of its contents not exceeding 1,500 words in length.

Illustrations should be drawn on drawing- or tracing-paper, to as small a scale as is consistent with distinctness, and figured dimensions should be introduced only where necessary. When an

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illustrated communication is accepted for reading, a series of Diagrams will be required so drawn and coloured as to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, will not be accepted. According to the By-laws every Paper presented to the Institution is deemed to be its property, and may not be published without the consent of the Council.

The Communications must be forwarded to the Secretary, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it may be dealt with in the succeeding one.

JAMES FORREST, *Honorary Secretary*,
J. H. T. TUDSBERY, *Secretary*.

THE INSTITUTION OF CIVIL ENGINEERS,
*Great George Street, Westminster, S.W.*
*May*, 1899.

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EXCERPT BY-LAWS, ARTICLE 3, SECTION XV.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

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## Notice.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors have advanced somewhat doubtful theories, or have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat that the Institution as a body must not be considered responsible either for the statements made, or for the opinions expressed in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

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# ORIGINAL COMMUNICATIONS

## RECEIVED BETWEEN 18 APRIL, 1898, AND 31 MARCH, 1899.

AUTHORS.

Airy, W. No. 3,169.—Note on the Paper on the Pressure of Grain. (Vol. cxxxvi.)

Aitchison, G. C. No. 3,168.—Mechanical Appliances used in Connection with the Snowdon Mountain Railway.

Anderson, C. W. No. 3,158.—Pile-Screwing by Hydraulic Process. With 2 Drawings.

Anderson, Sir W., the late. No. 3,144.—On some of the Properties of Cordite. (Vol. cxxxvi.)

Bamford, C. F. No. 3,118.—The Pahartali Locomotive and Carriage Works of the Assam-Bengal Railway. With 3 Appendixes and 7 Drawings. (Vol. cxxxv.)

———————. No. 3,163.—The Design and Construction of Railway Carriages in India. With 36 Drawings. (Vol. cxxxviii.)

Barber, T. W. No. 3,156.—The Victoria Bridge over the Dee at Queensferry. With 5 Drawings. (Vol. cxxxviii.)

Bonolis, A. No. 3,173.—Plant for the Production and Transmission of Electric Energy in Florence.

Chenhall, J. W. No. 3,136.—Coal Mining by Means of Mechanical Appliances. With 2 Tracings and 19 Photographs.

Cowper-Coles, S. O. No. 3,154.—Electrolytic Methods for the Treatment of Complex Zinc-bearing Sulphide Ores. With an Abstract and 25 Drawings.

Dalrymple-Hay, H. H. No. 3,174.—The Waterloo and City Railway. With 12 Tracings.

Dobson, J. M. No. 3,155.—Buenos Aires Harbour Works. With 5 Tables and 19 Drawings. (Vol. cxxxviii.)

Durston, Sir A. J., and Oram, H. J. No. 3,164.—Recent Trials of the Machinery of Warships, with results of experience on various points in connection therewith. With 12 Tables and 5 Drawings. (Vol. cxxxvii.)

Ende, M. am. No. 3,129.—Theory of Cable Bridges with Stiffening Girder. With 22 Drawings. (Vol. cxxxvii.)

Fox, F. No. 3,138.—Ventilation of Tunnels and Buildings. (Vol. cxxxvi.)

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AUTHORS.

**Fox, G. H.** No. 3,116.—Selangor Government Railway: notes on Construction and Working. With 4 Drawings.

**Glover, J.** No. 3,170.—Transition Curves for Railways. With 12 Drawings.

**Gordon, G.** No. 3,134.—Irrigation in Victoria.

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**Z.**

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## EXTRA MEETING.

20 April, 1899.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

## THE "JAMES FORREST" LECTURE.

The PRESIDENT said it was scarcely necessary to introduce Prof. Ewing, who was so well known to engineers, both as an authority upon the subject of his lecture and as the occupant of that chair at Cambridge which exercised such great influence on the rising generation of engineers. Before Prof. Ewing began, the President would like to mention that he had received a letter from their old and dear friend James Forrest, regretting that the state of his health prevented his presence on the occasion.

## "Magnetism."

By Professor JAMES ALFRED EWING, M.A., F.R.S., M. Inst. C.E.

WHEN the Council of the Institution honoured me with an invitation to deliver the "James Forrest" Lecture they suggested "Magnetism" as the subject. I felt at the time that it was like prescribing an ox roasted whole for an invalid's lunch. How could one treat a theme so vast within the limits of a single hour with any hope of making it pleasing or even digestible? But, having nothing better to propose, I weakly acquiesced, and I now find myself confronted by this appalling task. It gives me at least a grain of comfort to reflect that the Council must take a large share of responsibility for the choice.

Whatever be his subject, the particular duty of the "James Forrest" Lecturer is to treat it as an illustration of the bearing of science upon practice. He has to show how the visions of the philosopher become translated into the matter of fact of the engineer; how observations and theories which at first awaken only the intellectual interest of the scientific enthusiast are in time found to have application to the use and convenience of the man in the street. He has to show that if necessity is the mother



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of invention, science is often its foster-mother. And there is another side to the matter, for if the lecturer discharges his duty aright he will show how practice pays back its debt to science; how the progress of invention stimulates the progress of discovery; how the laboratory owes as much to the workshop as the workshop owes to the laboratory.

Time was when it might have been appropriate in addressing an audience of engineers to plead for the better recognition of science as the handmaid or mistress of practice. But there is no need to do that now. The service which each does to the other is recognized; the beneficent reaction between them has, in late years especially, been too fruitful to escape universal notice. Whatever barrier used to be apparent has broken down. Day by day, one may say, more and more points of contact are found, more grounds of sympathy in sentiment, more opportunity for co-operation. To one who, like your lecturer, has his affections distractingly divided between physics and engineering it is pleasant to note that not simply in education, but in language, in mental habit, in appreciation of experiment and in many other ways, engineers become daily more and more akin to physicists, while students of natural science grow more ready and more able to observe nature from the standpoint of the engineer. There will always, we need not doubt, remain two extreme schools of intellectual activity, one caring only for abstract truth, the other with no interest save for what promises immediate application. But between those extremes you will find men of more catholic spirit, whose zest for scientific discovery is none the less keen because they have an eye to the uses to which some of it may be put. The achievements in the world of practice of a Kelvin or a Hopkinson are as remarkable as their discoveries in pure science. I mention great names, but there are many lesser men who follow in their footsteps.

Certainly it would be difficult to find a subject that is better fitted to illustrate the harmony of practice and science than this subject of magnetism. Indeed, so intimate is their contact and co-operation here that it would be hard, in giving any account of the subject, to draw a line between matters of industrial application and fruits of research.

The applications of magnetism are older than the science—so old that they are lost in the mists of the remote past. If we cast our eyes far enough back they light on the traditional and shadowy figure of the Chinese imperial navigator Hoang Ti, who, some 24 centuries before Christ, is said to have piloted his fleet of conquering junks by the aid of a floating fragment of loadstone. The loadstone, a natural magnet composed of the magnetic oxide of

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iron, is found in the magnetized state at many places on the earth's surface, and notably at Magnesia, in Asia Minor, which led Euripides to call it the magnetan stone. Though the writings of Plato and Pliny and Lucretius contain many references to the distinctive properties of the loadstone and many curious legends concerning it, it is remarkable that neither the Greeks nor the Romans were aware of its use in navigation. We are told in the Book of Acts that St. Paul, after staying three days at Syracuse, "fetched a compass" and came to Rhegium, but any student of the Institution will tell you it was not a mariner's compass that he fetched.

Though the uses of magnetism were unknown in those classical times, its abuses appear to have flourished then, as they do still. The loadstone was reputed to free women from witchcraft and to put demons to flight. A magnet pickled with the salt of the sucking-fish could draw water from the bottom of the deepest well. Iron rings magnetized by rubbing against a loadstone were a remedy for the gout, and the priests of Samothrace, 5 centuries before the Christian era, are said to have made a tidy revenue by selling those ancient prototypes of the modern magnetic belt. The mysteries of magnetism have in all ages formed a happy hunting-ground for lovers of the occult. Quackery and superstition have found it a name to conjure with. The fact that a thing is unintelligible has been held sufficient reason for dubbing it magnetic. It is no part of my business to speak of "Animal Magnetism," for whatever elements of fact there are in the reported phenomena which go by that name, we may rest assured that with magnetism they have nothing whatever to do. It is a striking fact that among our bodily senses we have nothing to help us to a perception of magnetic activity. The sense of sight may indeed be called a magnetic sense when regard is had to the principle that light is made up of electro-magnetic waves, but you may put your hand or your head between the poles of the most powerful magnet and be unable to tell whether the magnet is or is not in action. We have no direct perception of the magnetic field, and there is no such thing in any legitimate use of the term as animal magnetism.

According to one story it was Marco Polo, the Venetian, who brought the mariner's compass from China to Europe in the 13th century. Anyhow its use was known then, though the attractive influence was wrongly localized, being ascribed to one of the stars in the tail of the Great Bear. The Provençal poet Guiot, in a MS. of the 13th century, tells at length, as if it were rather a new thing then, how a steel needle may be magnetized by touching



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it with a loadstone, and how when put through a piece of straw and set floating it always points to the north :—

"Puis se torne la point toute
Contre l'estoile sans doute."

A famous letter of Peter Peregrinus written in 1269 contains a remarkably good account of the polar quality of the magnet and of its use in finding the north. By the time of Columbus the compass, with its divided card, was apparently a common appliance in navigation. It was during his first voyage to America in 1492 that Columbus discovered the variable deviation of the needle from the true north. The fact that the balanced needle does not lie horizontally, but dips, was discovered by a London instrument maker called Norman in 1576.

We may take it, then, that applications of magnetism were known certainly 600, perhaps 5,000 years ago. But the science of magnetism is just 300 years old; it dates from the publication, in the year 1600, of the treatise "De Magnete" by William Gilbert. In that remarkable book the speculations of the schoolmen and the "old wives' tales" which had gathered about the subject were brushed aside, and the foundations of magnetic philosophy were laid on the safe ground of experiment. Gilbert showed, by means of a model globe cut out of loadstone, that the behaviour of the compass needle was to be explained by regarding the earth itself as a great magnet, surrounded consequently by an "orbis virtutis" —a sphere of influence, or, as we should now call it, a magnetic field. Time would fail me to tell you of the many acute observations described by Gilbert, which entitle him to high rank among the founders of experimental science. Galileo, his even greater contemporary, said: "I extremely admire and envy the author of 'De Magnete';" and Dryden wrote this panegyric :—

"Gilbert shall live till loadstones cease to draw,
Or British fleets the boundless oceans awe."

This last line suggests the remark that if Dryden could see the naval estimates for the present year of grace—and of aspiration after general disarmament—he would surely have no misgivings as to the permanence of Gilbert's fame.

It would be easy to occupy the whole of the lecture in telling of the subsequent developments of that first application of magnetism, the mariner's compass; of the new problems which presented themselves when magnetizable metals—iron and steel—took the place of timber in the construction of ships; of the analysis by Archibald Smith of the various disturbing influences

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which the magnetism of the ship exerts; and of the inventions by which Lord Kelvin brought the compass to its present state of perfection and enabled correcting devices to be applied by which the effects of the ship's magnetism are neutralised. In Lord Kelvin's compass we have a striking instance of the results that are achieved when profound scientific insight works hand in hand with rare practical instinct and inventive skill. I wish I could dwell on so attractive a theme, but I must hasten on to speak of other developments and applications of the science of magnetism.

The pivoted needle of the compass turns so that it may place itself in the direction of the lines of force of the magnetic field; so long as no local disturbing cause acts, the field is that due to the magnetism of the earth. But Oersted discovered, in 1820, that if a wire conveying an electric current were brought near, the needle became deflected, because (as we now know) the current produces a magnetic field on its own account, whose lines of force encircle the conducting wire. Eleven years later Schweiger showed how this effect could be intensified by winding the conductor into a coil, in the middle of which the pivoted needle was set, and thereby invented the galvanometer. The laws of the phenomenon were investigated by Ampère and by Weber, and thus the way was paved for the introduction in 1837 of the needle telegraph by Cooke and Wheatstone. Our President has lately told us of their pioneer line 1½ mile long, part of which was revived by him and was used, as a relic of the year of the Queen's accession, to telegraph Her Majesty's message to her scattered peoples on the day of her Diamond Jubilee. What that lusty infant, the telegraph, has grown to in the intervening 60 years you do not need to be told. Taking British telegraphs alone, the expansion of which owes much to our President's fostering care, there are now considerably more than 1,000,000 miles of wire. Our distant colonies are bound to the mother country not simply by links of loyalty and mutual affection, but by material bonds of copper which have no small part to play in the building up of Empire.

The suspended needle, by which Cooke and Wheatstone gave practical application to the discovery of Oersted, did not long remain the sole, or even the chief, instrument in telegraphy. It was almost at once supplemented, and soon to a great extent displaced, by the family of instruments which depend on the attraction which an electromagnet exerts on a movable armature, instruments of which the telegraph of Morse was the first to take working shape. But Oersted's discovery met with a second great application at the hands of Lord Kelvin in 1858, when the problem of signalling at a remunerative speed through long

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ocean cables was solved by his invention of the mirror galvanometer, an invention which, at the same time supplied physicists with an invaluable new weapon of research. His later invention of the siphon-recorder allowed the delicate fluctuations of current, which constitute the signals in such a cable, to be registered as well as read. In the galvanometer the coil is held fixed and the magnet moves. In the Kelvin recorder the force between the two is still the operative force, but it is the coil that moves while the magnet is held fixed.

Morse's telegraph was the practical fruit of the discoveries of Ampère and Sturgeon. Ampère had shown that pieces of steel might be permanently magnetized by placing them inside a coil of wire, within which a magnetic field was established by passing an electric current through the wire. Sturgeon, in 1825, substituted a soft-iron core for the steel, and pointed out that it acquired strong magnetism so long as the current flowed through the surrounding coil, but lost its magnetism when the current ceased to flow. On establishing the current the iron core underwent, as he says, a "transition from a state of total inactivity to vigorous polarity," and exhibited "an intensity of action far surpassing that of any known permanent magnet." Joseph Henry improved the winding of Sturgeon's electromagnet and used it, by means of a movable armature, to sound a bell at a distance from the operator. From this the step was easy to the recording telegraph of Morse. Simplified into the "sounder," this remains one of the most ordinary appliances of the telegraphist, and the principle it embodies finds application in the Wheatstone automatic receiver, in the type-printing telegraph familiar to those who study the "tape," and in a host of other forms.

Faraday's discovery, made in 1831, that a current of electricity is induced in a conducting circuit when it is moved in a magnetic field, in such a way as to vary the number of lines of force which it encloses, led to the invention of the magneto-electric machine, where the movement of the armature of a permanent magnet is used to induce currents in a coil. This has found many uses. It was applied in telegraphy by Wheatstone as the transmitting device in his step-by-step or A B C apparatus. Substantially the same principle formed the basis of the original telephone of Graham Bell. There the movement of an iron disk by the speaker's voice induced corresponding currents in a coil, through the agency of a magnet to which the disk acted as armature, the movements of the disk having the effect of varying the magnetic field within the coil. These currents passed to the distant end and gave rise to corresponding movements on the part of a second

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disk, in an instrument which was an exact counterpart of the first. I was old enough in 1876 to appreciate the charm of this weird and exquisite invention, and looking back now, it seems, as it seemed then, alike in its novelty, in the vastness of its consequences and in the simplicity of its means, to be the most marvellous of all the wonder-compelling applications of magnetism. The magneto-electric method of generating telephone currents, introduced by Bell, gave place, in the hands of Edison and Hughes, to other and better means, but the receiving portion of the apparatus retains substantially the form which he gave it. The varying attraction for its armature of a magnet which is strengthened and weakened by the transmitted currents is still used to cause the vibrations of the disk which convert those currents into speech. The latest advance in telegraphy, the achievement of Marconi in communicating between France and England without an intervening wire, is as much as any other a direct fruit of magnetic research. When an electric current comes into existence the magnetic field which it induces around it does not spread through space instantly but with a limited velocity. A current undergoing rapid oscillations, such as a discharge surging back and forth between two plates, consequently sets up magnetic waves of corresponding frequency which travel out into space with a velocity which is, in fact, the velocity of light. These waves of magnetic induction were pictured by the mathematical imagination of Maxwell; and they were demonstrated by the experiments of Hertz, who showed us how to detect their presence at points which might be fairly distant from the source. The researches of Branly and Lodge gave far more delicate means than Hertz had used to discern the arrival of these magnetic waves; and Lodge, who has devoted much attention to the subject, has also been successful in developing appliances for sending and receiving signals over long distances by comparatively long-period waves of magnetic induction, using closed circuits at each end of the system, tuned into electric synchronism, so that the magnetic oscillations sent out by one of them are detected by aid of electro-magnetic resonance in the other. In this connection reference should be made to the pioneer work of our President, Mr. Preece, who in 1895 used magnetic induction to maintain telegraph service across the Sound of Mull—a distance of some 2 miles—for a week or more while the cable was interrupted. The same system is now in permanent practical use as the means of telegraphing to the Island of Flat Holm in the Bristol Channel. But the most striking success which has been achieved in this application of magnetism is Marconi's use

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of short-period Hertzian waves to signal across the channel from the South Foreland to Boulogne. Mr. Marconi is to be warmly congratulated on accomplishing this remarkable feat, which has arrested the attention alike of the public and of specialists, and had opened all eyes to the practical capabilities of this new telegraphy.

It is interesting to note in passing, though it is scarcely relevant to my subject, that telegraphy by waves of magnetic induction is the oldest telegraphy of all. Maxwell's conclusion that the waves which constitute light are nothing else than very quick-period waves of magnetic induction was abundantly verified by the work of Hertz, who succeeded in submitting artificial magnetic waves to the reflection, refraction and polarization, which we are familiar with in the case of light. Hence the heliograph, the venerable semaphore, and all the visual signals that have been used from the day when Eve first smiled to Adam, are examples of magnetic wave telegraphy, though I cannot claim them as fruits of magnetic research. In the use of that most delicate of electromagnetic receivers, the eye, we must admit that practice came before science.

Faraday's great discovery of the induction of electric currents by moving a conductor in a magnetic field of force led, as we have seen, to the magneto-electric machine. A permanent steel magnet served to produce the field, and the coils in which current was induced were generally wound upon an armature, which revolved between the poles. The early machines of Clarke and Pixii were improved upon by Wilde, who used a second machine to generate a current which was employed in magnetizing the field-magnets of the first. From this to the invention of the dynamo was a step so natural that we need not wonder it was taken independently, and almost simultaneously, about the beginning of 1867, by no fewer than three inventors, Wheatstone, Werner Siemens, and Alfred Varley. Up to that time the magneto-electric machine, when considered from the engineer's standpoint as an engine for producing electrical energy by the expenditure of mechanical work, had been little more than a toy. But the abolition of permanent magnets, and the substitution of soft-iron cores excited by the current generated in the machine itself, constituted a revolution; and the dynamo became a means of applying power to generate electric currents on a grand scale. I do not mean that the change came all at once; it is a far cry from the "'A' Gramme" of 20 years ago to the big dynamos of to-day, with their 2,000 HP. or 3,000 HP. But the introduction of the self-exciting field magnet was the decisive step which made the

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mechanical production of electric currents a part of engineering—a large part, indeed, as it has since become.

The dynamo machine underwent a course of improvement which was, in part, the necessary consequence of its design being seriously taken up by mechanical engineers, but in great part also the result of magnetic research. To no man did it owe more than to one who was lately taken from us in the fulness of his powers and in circumstances of peculiar sadness. John Hopkinson's contributions to the development of the modern dynamo were many, but I would specially refer here to his part in establishing the theory of the magnetic circuit. Though the idea of the magnetic circuit had been more or less vaguely present, mainly by analogy, in the minds of other thinkers it was for the first time explicitly formulated in a way to command assent in a Paper by the brothers John and Edward Hopkinson, and was further applied by them with remarkable effect to problems of dynamo design. A right appreciation of the principle of the magnetic circuit has been one powerful factor in the evolution of the modern dynamo. Another has been the advance which has taken place, through experimental research, in our knowledge of the magnetic qualities of iron. I shall endeavour, before we have done, to pass in rapid review some of the principal facts in magnetism with which the dynamo builder is concerned.

Imagine a conductor wound into a coil which carries an electric current. Each of the lines of force, or, as we will rather call them for the present purpose, lines of magnetic induction due to the current, passes through the interior of the coil and returns into itself through external space. The path taken by these lines constitutes the magnetic circuit; it is interlocked with the circuit of the conductor, and in this instance it fills all space, for the lines returning outside the coil are spread without limit. Imagine next that the coil is a long helix and that it is bent round to form an endless ring. The lines of induction are now confined to the interior of the ring; they still form a closed circuit interlocked with the circuit of the conductor, but they now close themselves without spreading into outside space. If we strengthen the current in the coil we strengthen the induction in the magnetic circuit. If we fill the space within the coil full of one substance or another we find in general very trifling variations in the induction within. But if one of the three metals, iron, nickel or cobalt, be placed as a core within the coil, especially if the one chosen be soft iron, we find an enormous difference. The induction within the coil is then many times greater—it may even be thousands of

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times greater—than it was before the iron was put in. This familiar fact is expressed by saying that iron and, in a lesser degree, nickel and cobalt possess exceptional permeability to magnetic induction.

A core of iron, however strongly magnetized, would be of no service in a dynamo unless we imagine a gap to be cut in it, where the conductor, whose movement across the lines of induction is to produce current, can be placed. The practical function of the field-magnets is simply to produce a strong induction in the narrow gap where the armature-coils revolve. The business of the fixed coils, to which the magnetization is due, is to establish a mixed magnetic circuit, forcing the magnetic induction not only through the iron, but across the much less permeable gap. Hopkinson's discussion of the magnetic circuit showed how it might be arranged in the way most favourable to efficiency, and how, knowing the dimensions of the system and the magnetic quality of the iron, we could predicate what amount of magnetic induction would be set up in the gap by a given current in the field-magnet's coils, and hence predetermine the behaviour of the machine.

No sooner was the dynamo introduced than it was discovered that its function could be reversed. Given a supply of electric current, the dynamo, acting as a motor, would serve to convert the energy of the current into mechanical work. This opened up an immense additional field for the industrial uses of magnetism. I need not take up time by referring to matters of everyday observation. No one does not know how the dynamo, acting both as generator and as motor, has given us a new branch of engineering of so vigorous growth that it almost threatens to eclipse the parent stem. It has given us electric lighting and the electric distribution of power. It has taught us to harness Niagara, where I was glad to see that the engineers have still left some water, and other waterfalls, where I am sorry to think they have left none. It has created new metallurgical processes and new chemical manufactures with the aid of the electric furnace and the electrolytic vat. It has given us electric railways and tramways, or, rather, it has given them to our neighbours on the continent and our friends over the sea, for you will find more electric traction in a single American or Canadian city than in the whole of Great Britain.

Faraday's further discovery that the induction of magnetism in an iron core by setting up a current in a surrounding coil would induce a current in a second coil wound upon the same core was the parent of the induction-coil and the transformer. Alternating currents in the primary circuit produce reversals of magnetism in the core, and thereby induce corresponding alternating currents

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in the secondary circuit, the ratio of electric pressure between the two depending on the number of turns in the winding of the two coils. It is to the induction-coil that we owe the high-pressure currents required for Hertzian telegraphy, and for the Röntgen rays. The transformer—an induction-coil with a core closed upon itself to form a complete magnetic circuit in iron—gives the engineer means of economically conveying electric energy over long distances, by first raising it to a pressure which may be transmitted with but little loss in a long conducting wire of moderate size, and then lowering it to a pressure at which it may be utilized without inconvenience or danger. The principle found its earliest engineering embodiment in the crudely designed "secondary generators" of Gaulard and Gibbs. Here we have another notable application of magnetism, and it may be added that it is by applying magnetic theory and magnetic experiment that the conditions are practically arrived at which allow the conversion of electricity by the transformer to be performed efficiently. Here, too, a study of the magnetic qualities of iron is all-important to the electrical engineer.

A few incidental applications of magnetism to engineering purposes remain to be briefly mentioned. The attraction across a surface of division between two parts of a magnetic circuit, originally investigated by Joule in 1838, is made use of in the workshops in a variety of ways. Magnetic crane-hooks are employed to lay hold of and lift heavy plates. Drills and other tools are attached by magnetic attraction to the piece on which they are to work. Magnetic clutches serve to connect and disconnect lines of shafting. Magnetic brakes have been applied to the wheels of vehicles. In all these cases the force which is taken advantage of is due to magnetization; it comes and goes with the making and breaking of the magnetizing current, and it may readily be made to amount to nearly 200 lbs. per square inch.

Thermo-magnetic engines have been devised to perform directly the conversion of heat into work. A piece of iron heated to bright redness (say 780° C.) loses nearly all its capacity for magnetic induction and ceases to be attracted by a magnet. It may therefore be withdrawn from the neighbourhood of a magnet pole without expenditure of work; but once the iron is cooled the magnet resumes its attraction. Hence by heating the iron when it is in a strong field, then removing it while hot to a place where the field is weaker, then cooling it till the magnetic action re-asserts itself and then allowing it to return, we take it through a cycle in which mechanical work is done by it, work which may be applied to a

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useful purpose by appropriate means. The energy to do the work comes from heat, more heat being absorbed in the heating of the iron than is given out in the cooling. But though it is easy to make a working model which will illustrate the principle of this action, the task of making an engine which will carry it out efficiently on a practical scale has not been accomplished, nor is it in the least likely of accomplishment.

Yet another application of magnetism, and one with a more promising future, is the use of the magnetic field in separating magnetic from non-magnetic substances. A familiar instance is the workshop process of separating iron filings and turnings from brass. Edison has lately turned this idea to practical account by employing magnets in the concentration of iron-ore. One of the most widely diffused ores of iron is the magnetic oxide—the material of the loadstone—which is susceptible to magnetic induction, and is therefore attracted by the magnet. In most cases it is so much intermixed with foreign matter that to smelt the mixture would not be remunerative. Edison's process renders it possible to work such low-grade ore economically. He first grinds it, and for the operation of grinding he has devised machinery remarkable for its boldness in conception and its ingenuity in detail. He then causes the ground mass to fall in a stream before the face of a magnet which deflects the particles that are capable of attraction; so that, while the earthy matter continues to fall vertically, the concentrated ore falls to one side and is separated out. In practice the crushing and magnetic separation proceed in a long series of stages. Through this process of concentrating low-grade iron-ore by magnetic winnowing, as one may call it, Edison hopes, and apparently not without reason, to unlock vast natural stores of iron which have hitherto been unavailable, and he has shown the courage of his convictions by spending great sums on the plant by which the process is now being tested on a commercial scale. His crushing and separating machinery at the town of Edison, New Jersey, is able to deal with 5,000 tons of ore a day, and it is said to produce a concentrate containing 67 per cent. of iron from crude ore containing only 20 per cent. An English syndicate has taken up this matter, and, though the prospectus is not yet brought to the birth, the prospector is already at work searching in the Scottish highlands for beds of mixed magnetic ore. In this search he is guided in the first place by the magnetic survey of Rücker and Thorpe, expecting, *primâ facie*, to find deposits of ore where they have detected local perturbations of the terrestrial magnetic field. Here we have an example of what occurs over and over

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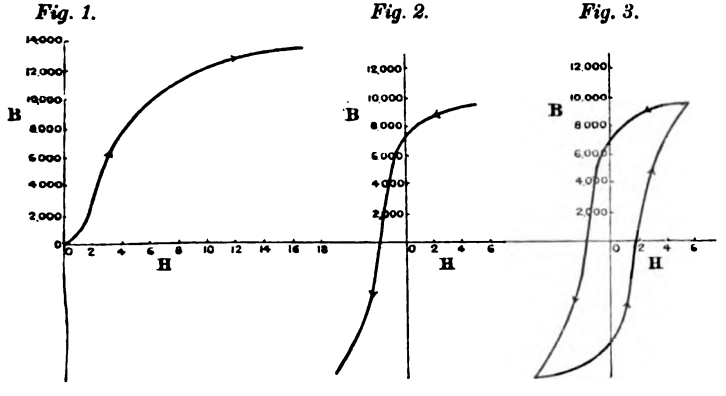
again in the history of scientific discovery. A utilitarian application unexpectedly follows a piece of scientific research which at the time it was made seemed to have none but the most abstract interest. In the evolution of engineering few things are more conspicuous than the ultimate usefulness of "useless" knowledge.

The electrical engineer requires special iron to derive the best results in his dynamos and transformers, and the supply of it has become an important industry. The carbon and manganese which are essential in steel that is intended to be strong, are prejudicial in steel that is intended to be magnetic. Special steel castings, consisting of almost pure iron, now supply the dynamo builder with a material that is excellent in magnetic quality, and, being cast, they are readily supplied in appropriate




MAGNETIZATION OF IRON.

shapes for the field-magnets. Special iron or steel is rolled into sheets and stamped into the forms which are wanted for the armatures of dynamos and the cores of transformers, and the magnetic quality which it possesses is immensely superior to that of any iron which could be obtained a few years ago. The testing of iron for magnetic quality, which within my own experience was a matter of original research, is now an everyday operation in the workshop, and iron is ordered to specification of its magnetic properties, just as in other departments of engineering it is ordered to specification of its strength.

In the magnetization of iron we are concerned mainly with two properties—one is permeability, or the readiness with which the metal takes up magnetic induction, the other is a property to which some 18 years ago I gave the name of "hysteresis," after

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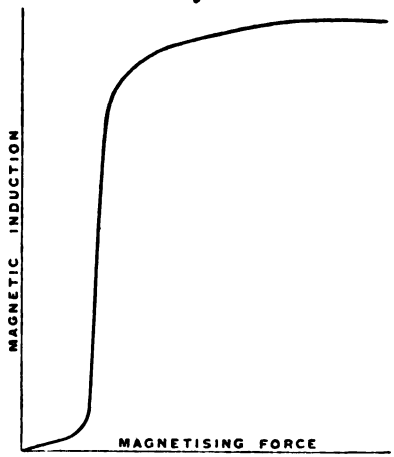
an investigation that was undertaken without any idea that the property in question would come to be commercially important. To understand what happens when iron is magnetized, consider again a ring of iron forming the core on which a magnetizing coil is wound. A current passing through the coil subjects the ring to magnetizing force, which increases in simple proportion as the current is increased. But the magnetic induction within the core does not increase proportionately to the magnetizing force. Let the magnetizing force be gradually raised. At first the increase of induction is slow, then very rapid, then slow again. You observe three more or less clearly marked stages in the process (*Fig. 1*), and in special cases you may see the three very sharply distinguished from one another, as in *Fig. 4*, which exhibits the magnetization of a piece of nickel under certain conditions as to stress. Thus the permeability of iron is a variable quantity, comparatively small for small magnetizing forces, very large for forces of medium intensity, and then comparatively small again when the force is strong. In all three stages, however, the induction increases faster than the magnetizing force increases. But by using exceedingly strong forces we find that a fourth stage is reached, in which the increase of induction is only equal to the increase of magnetizing force. When that happens the iron is said to be saturated. After that it has no greater power of taking additional induction than a piece of brass or wood. Engineers have nothing to do with that extreme condition of magnetization. In the transformer and the dynamo we are concerned only with what I have here called the second and the third stages of the process.

*Fig. 4.*




MAGNETIZATION OF NICKEL IN A STATE OF TORSION (NAGAOKA).

Next, suppose that after the magnetizing force (H) has been raised to any value, it is reduced, say to zero (*Fig. 2*). We find that the magnetic induction (B) also becomes reduced, but by no means so much as you might expect. It tends, in great measure, to persist and a good part of it survives the complete withdrawal of the

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magnetizing force. Let the process be continued by applying magnetizing force in the opposite direction to the first, and then let the force be again removed and reversed. We thereby get the cyclic process of change illustrated in *Fig. 3*. Throughout this process the changes of induction lag behind the changes of magnetizing force, and it is this lagging behind that is called hysteresis.

Residual magnetization is one of the consequences of hysteresis, and when steel is wanted for permanent magnets the maker has to aim at getting as much hysteresis as possible, which he generally does by putting in some tungsten. But in most of the magnetic uses of iron it is desirable to reduce hysteresis to the uttermost. This is notably true of dynamo armatures and the cores of transformers. In the core of a transformer the magnetism goes through repeated cycles of reversal, such as the cycle shown in *Fig. 3*, often as frequently as 100 times a second. Now every such cycle means an expenditure of energy, which is greater the greater the hysteresis. It is easy to prove (as was first done by Warburg) that the area enclosed by the two curves which make up the cyclic process is a measure of the work that is spent upon the iron. That work is wasted; it is simply dissipated as heat. The efficiency of a transformer consequently depends on this, more than on anything else, whether the core is made of iron having little hysteresis. Various specimens of iron differ very widely in hysteresis as well as in permeability, and hence the practical importance of magnetic tests.

The methods by which the permeability and the hysteresis of iron were at first investigated were laborious, even in the hands of people used to physical research. Several inventors have applied themselves to the task of providing simpler means of making such measurements. Having some personal experience—which began earlier than most people's—in this matter of magnetic testing, I have endeavoured to provide apparatus suitable for workshop use. Three of the instruments devised with this object are before you. The first is a Hysteresis Tester, which has come into extensive use for measuring directly the hysteresis of sheet iron such as is employed in the cores of transformers and dynamo-armatures. The specimen is a little bundle of strips and it is made to revolve between the poles of a permanent magnet which is free to swing upon a knife-edge. At each half turn the magnetism in the specimen, induced by the permanent magnet, is reversed, and this reversal involves hysteresis, which shows itself by making the magnet become deflected over more or less. The amount of the deflection is read off by a pointer on a scale above, and

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gives a very simple measure of the hysteresis.[1] The second instrument I call a Permeability Bridge.[2] It allows tests to be made of the permeability of forged iron or cast steel in a way that is analogous to the measurement of resistance by Wheatstone's Bridge. The specimen is turned in the form of a rod, and is tested against a standard rod of the same size whose permeability curve has been determined beforehand. What the bridge actually determines is the ratio of the magnetizing forces which will produce the same magnetic induction in the two rods, and by making this comparison for several different strengths of magnetizing current we have data for drawing the permeability curve for the rod under test. The process performed in this way is immensely simpler than the older method of testing, and it gives the curve as completely as may be desired. But under the impression that something even more rapid and direct would be useful, I lately brought out a third instrument, the Magnetic Balance, which by, so to say, weighing the attraction between the test-bar and a fixed magnet allows the induction produced by a particular value of the magnetizing force to be read directly upon a divided scale.[3]

The various stages in the process of magnetization, and the character of magnetic hysteresis, will be made more intelligible if I show you in action another instrument which I call a Magnetic Curve Tracer, which enables the motion of a small mirror to exhibit magnetic curves upon a screen. The mirror receives two components of motion; it turns horizontally by amounts which are proportional to the magnetizing force, and vertically by amounts which are proportional to the magnetic induction in a magnetic circuit of iron which forms part of the machine. Hence a spot of light reflected on the screen from the mirror traces out a curve which shows how the induction changes as the magnetizing force is changed. By reversing the magnetizing current repeatedly we make the iron go over and over again through a cyclic process of magnetic reversal, with the result that the spot of light traces out a closed curve showing hysteresis and having all the characteristics of *Fig. 3*. The moving parts of the instrument are

[1] For a description of the hysteresis-tester, see Journal of the Institution of Electrical Engineers, 1895, p. 398; also Minutes of Proceedings Inst. C.E., vol. cxxvi. p. 206.

[2] Minutes of Proceedings Inst. C.E., vol. cxxvi. p. 201. A description of the present form of the permeability bridge will be found in *The Electrician*, vol. xxxvii. p. 41.

[3] Journal of the Institution of Electrical Engineers, 1888, p. 526.

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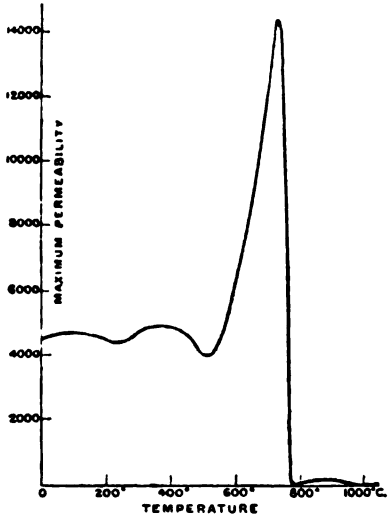
made very light, so that I can quicken the process sufficiently to make the path of the spot appear, by persistence of vision, as a continuously luminous curve.

There are many interesting features of the magnetizing process on which, if time permitted, we might dwell. Effects of stress and effects of temperature have been very fully examined, with results which, in some particulars, are of practical import. One point which deserves special notice, on account mainly of its physical interest, is that when we change the state of a piece of iron that is being magnetized, whether by heating or cooling, or by pulling, or pushing, or twisting, or vibrating it, the first effect of the change in temperature, or in stress, is to reveal a certain instability in the magnetism, and it is only after several repetitions of the change of state that things settle down and the proper effect of the alteration in condition exhibits itself. This is a phenomenon closely associated with hysteresis, and we shall see presently that the molecular theory which explains hysteresis explains it also.

*Fig. 5.*




EFFECTS OF TEMPERATURE ON THE PERMEABILITY OF IRON (MORRIS).

The effects of temperature on magnetic quality have a direct bearing on some of the engineering applications of magnetism. Some of those effects are immediate, and some only show themselves when the iron has been heated for a considerable time. The immediate effects of heating were examined by Hopkinson, and more lately they have been the subject of an excellent investigation by Mr. D. K. Morris. Briefly, the general effect of heating is to increase the permeability and reduce the hysteresis of iron until a certain critical temperature—about 780° C.—is reached, when iron loses nearly all its power of being magnetized. The change happens somewhat suddenly, for at temperatures only a little lower than that the permeability is very great and the hysteresis exceed



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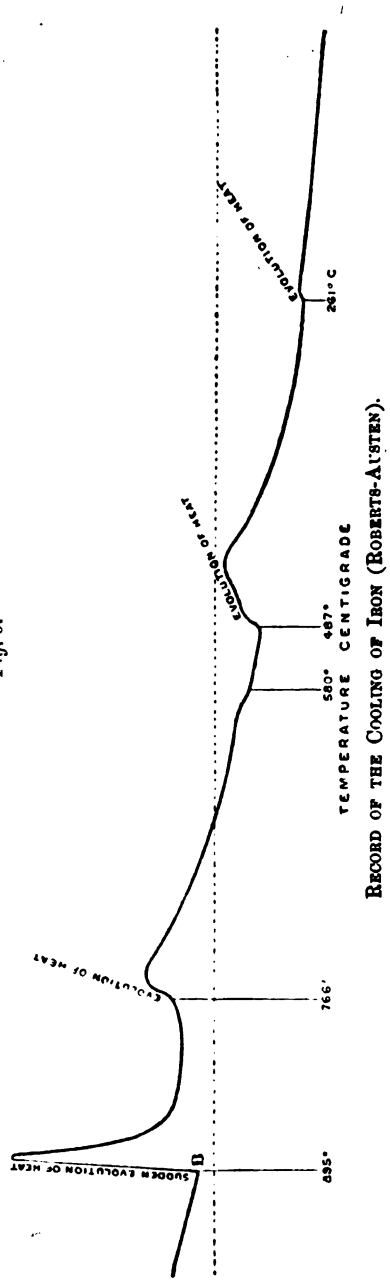


*Fig. 6.*

RECORD OF THE COOLING OF IRON (ROBERTS-AUSTEN).

ingly small. The curve, *Fig. 5*, taken from Mr. Morris's Paper, shows how the maximum permeability alters as iron is heated. There is a general rise in permeability, subject, however, to several set-backs in the course of the rise. The first of these happens about 250° C., the next between 400° C. and 500° C., and the greatest about 760° C. Now compare this with the curve shown in *Fig. 6*, which represents one of Sir W. Roberts-Austen's beautiful investigations of the rate at which a piece of iron cools from a white heat. There is a steady fall of temperature except at certain places where some internal convulsion happens which is associated with the giving out of heat. Note the points where this occurs, and you see that they connect themselves with what I have called the set-backs in the other curve. We may even trace a connection between the highest of these breaks and a change which is slightly apparent in Morris's curve about 900° C., though the iron then retains very little magnetic quality at all. The inference seems pretty plain that not only at the great magnetic critical point is there a transformation of structure associated with absorption of heat

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during the heating of the iron, but that a similar connection holds at the other points of arrest.

But it is with the effects of long-continued heating that engineers are more concerned. It was observed that transformers lost some of their efficiency after they had been kept at work for some weeks or months, and that this was due to an increase of hysteresis in the iron core. Mr. Mordey proved that this increase of hysteresis resulted from the prolonged baking of the iron; a transformer at work becomes warm, largely because of the heat developed through hysteresis, and long exposure to a somewhat high temperature gradually alters the iron for the worse. The amount of this deterioration depends much on the degree of heat, and it is by no means the same for all specimens of iron; sometimes iron which is at first particularly free of hysteresis is most affected. Mr. Roget, who has investigated the matter in my laboratory, has found that continuous exposure for 7 days to a temperature of only 160° C. has actually trebled the hysteresis of one very good specimen; but, what is most curious, a further continuation of the baking at the same temperature causes improvement to set in. The hysteresis passes a maximum, which comes earlier the higher the temperature of the baking, and then tends to lessen when the baking is further prolonged. The curves *Figs. 7* and *8*, relate to a ring of sheet-iron heated at 200° C., and show the kind of change which happens, as well as how the changes in hysteresis are associated with corresponding change in the permeability of the iron. At that temperature the maximum is passed after a comparatively short period of baking.

This augmentation of hysteresis is a serious matter in transformers, and much attention has been given to getting iron which will not show it. Some specimens were lately submitted to me which were not only extraordinarily free from this objectionable characteristic, but had much less hysteresis even initially than any iron I had tested before. Makers are naturally reticent as to the processes of manufacture by which such results are obtained, and they have in some cases an additional and excellent reason for reticence in the fact that they really do not know what the conditions are to which the good results are to be ascribed. It is probable that light will be thrown on these difficult questions by the application of the microscope, a tool the value of which the metallurgist is now fast coming to recognize.

Much that is obscure in the phenomena of magnetization is made plain when we come to consider the molecular theory of the process. It is an old idea, due originally to Weber, that the



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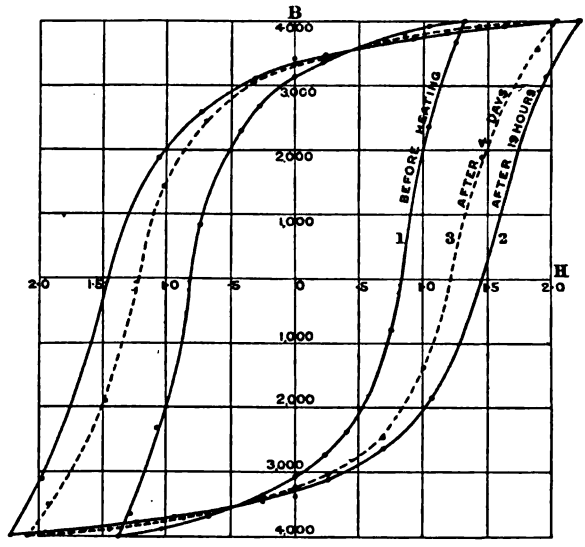
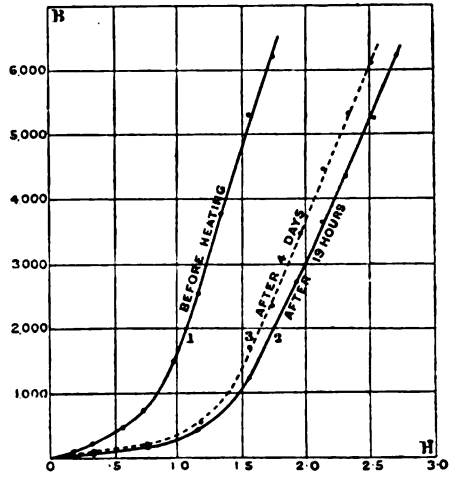
molecules of iron are always magnets, and the process of magnet-

*Fig. 7.*




EFFECTS OF BAKING OF THE HYSTERESIS OF SHEET IRON (ROGET).

*Fig. 8.*




EFFECTS OF BAKING ON THE PERMEABILITY OF SHEET IRON (ROGET).

izing a piece of iron is merely to turn the molecular magnets round so that they face one way. At first they are pointing every

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way at random, but when magnetizing force is applied they gradually turn, and finally, when saturation is attained they all lie with their magnetic axes exactly along the line of force. To account for their not all turning at once, and also for the fact of residual magnetism, various hypotheses have been framed, as, for instance, that the turning of each molecule is resisted by what may be described as a miniature friction-brake. A good deal of meditation on this matter led me to the conclusion that no such hypothesis was needed. The gradual turning of the molecular magnets and all the phenomena of hysteresis are simply results of the mutual actions between each molecule and its neighbours. We may demonstrate this by means of a model consisting of a large number of permanently-magnetized needles set on pivots near together. When a weak magnetic field is applied, the pivoted magnets turn slightly and in a quasi-elastic manner, free from hysteresis; but as the field is strengthened the ties between them are overcome and instability ensues, the original groups break up, and the magnets enter into new combinations. Finally, as the applied field becomes stronger still, complete parallelism is gradually approached.

Thus the model reproduces with perfect fidelity what I have called the three stages of the magnetizing process. Moreover, the dissipation of energy involved in the breaking up of molecular combinations corresponds exactly to what we know of hysteresis. The model shows not only how this cause of hysteresis affects a cyclic process of magnetization, but how it explains the instability which I mentioned as the first thing noticed when we heat, or cool, or stress a piece that is being magnetized. Any change of condition precipitates the breaking up of groups which were so to speak hesitating on the verge. By using a model with a large number of little magnets, we get the aggregate external magnetic effect of the group to vary with variations of the field exactly in the way in which the magnetism of iron varies, and the model indicates not only the main, but even the minor features of the process. It was pointed out by Mr. James Swinburne that my theory would involve this curious result, that a piece of iron when revolved in a very strong magnetic field would exhibit no hysteresis, though it shows much hysteresis when revolved in a weaker field. The prediction was experimentally verified by Professor Baily. We may illustrate this in the model by turning round the plate which carries the little pivoted magnets, when you will notice that breakings up of molecular groups occur when the field is weak, but not when the field is strong.

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I think this model has a bearing on other physical matters which concern engineers. It is easy to believe that between the molecules of materials there are other polar forces acting, distinct from magnetic forces, and common to non-magnetic as well as magnetic materials. When we make one body slide on another, these intermolecular forces acting across the surface of contact may cause the molecular groups near the surface to become broken up and reconstituted, thereby giving rise to the dissipation of energy which we are familiar with under the name of friction. The action will be apparent if we make one group of the little pivoted magnets slide past another group. We may go further and say that all non-elastic deformation of solid bodies by strain is probably an action of the same kind. Experiments which I have lately carried out, in conjunction with Mr. W. Rosenhain, have shown that the plastic straining of metals occurs through a multitude of separate slippings of one part on another, in each of the crystalline grains of which the metal is made up. The model may be taken as illustrating how with molecules possessed of polar forces such slips involve an expenditure of work. But this is taking me away from my already too comprehensive text.

I have tried in this hurried sketch of a great subject to show how in some cases invention has followed as the fruit of discovery, while in others discovery has resulted from the interest created by invention. One word in closing to the student of research. Do not think that in magnetism, because much has been done, nothing is left to do. The upper workings of the mine may be exhausted; but there are deep levels whose wealth is unexplored. Every point gained is a starting-ground for fresh inquiry. The patient and intelligent worker may rest assured that his labours will find a return, not perhaps in profit or in fame, but in that pure impersonal joy of discovery which, as those who have tasted it know, is the investigator's best reward.

Mr. W. H. PREECE, C.B., President, in proposing a vote of thanks to the lecturer, referred to the part played by woman in the introduction of wireless telegraphy. It was Agamemnon's notification to Clytemnestra of the fall of Troy that constituted the first recorded message by telegraph. The lecturer had taken them through a great many of the practical applications of magnetism, and while it would be dangerous to raise a dispute with one who was so complete a master of his subject, the President would venture to break a lance with him over one point. Prof.

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Ewing had commenced by saying that the principles and the practice of the engineer were entirely indebted to the scientific men; but towards the middle of the lecture the President was relieved to find in some instances practice came before science. He did not wish to say one word to decry that which was their servant—not their master—and they were proud when they succeeded in getting a man of science of such eminence as the lecturer to direct their attention to those branches in which he had played such an important part. Yet Prof. Ewing himself had been for a long time an eminent practical engineer before he accepted the Chair of Applied Mechanics at Cambridge, and he fancied that in the Professor's inmost heart there existed a consciousness that he owed much of his scientific knowledge to his early practical experience. He had charmed them by his discourse; his experiments and his models must have carried conviction to every mind. With great pleasure he proposed a vote of thanks to the lecturer for his interesting and eloquent address.

Sir JOHN WOLFE BARRY, K.C.B., Past-President, seconded the vote with equal pleasure. A point of special interest was that the lecturer was at the head of the engineering classes at Cambridge and was equipping the engineers of the future for the battle with these forces of Nature which all engineers would have to fight. No doubt these recondite investigations would play a very important part in the science of engineering in the future. Although he was disposed to agree with the President that some of their forefathers only dimly grasped these properties of matter which were now understood more plainly, yet they all knew that that which was recondite to-day would be the A B C of science to-morrow. He had the greatest possible satisfaction in seconding the motion.

The motion was carried by acclamation.

Professor EWING in acknowledging the resolution, said that but for the lateness of the hour he would be inclined to take up the President's challenge. He had stated that there was a double purpose which the James Forrest lecturer had to keep in view. First, to show the debt which practice owed to science; and, secondly, the debt which science owed to practice. In the matter of magnetism the debt which science owed to practice was so very obvious that he had not thought it necessary to dwell upon it in any detail.

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## Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 3176.*)

# "Experiments on Alloys of Iron and Nickel."

By Floris Osmond.

(Translated by A. Sharp, Assoc. M. Inst. C.E..)

Independently of the practical applications which have been made, and which may be found in the future, nickel-iron alloys are of considerable interest in connection with the physics of steel. The following Paper is devoted to a description of experiments carried out by the Author upon a series of specimens of alloys of iron and nickel, kindly supplied by Mr. R. A. Hadfield, M. Inst. C.E., with the object of investigating the critical points of the alloys, the appearance and disappearance of magnetism, the microstructure, and the magnetic properties at ordinary temperatures.

### Critical Points.

The critical points were determined, as in previous researches,[1] by the methods of heating and cooling. Two square bars about 40 millimetres long and 6 millimetres to 7 millimetres side, containing between them the terminals of a Le Chatelier thermo-electric couple, are submitted to a uniform heating or cooling, the time taken for the temperature to rise or fall one degree on the pyrometric scale being observed. In the curves of Plate 2 illustrating Mr. Hadfield's Paper on "Alloys of Iron and Nickel,"[2] the times are taken as ordinates, the temperatures corresponding to the divisions of the pyrometric scale as abscissas. The coolings were conducted in a Leclercq-Forquignon furnace, the specimen being placed at the middle of the furnace between two asbestos plugs. The desired temperature being reached, the gas- and air-valves are closed, the cover is removed, and the apparatus left to cool; this is called normal cooling. If the normal cooling is too

[1] Journal of the Iron and Steel Institute, 1890, part 1, p. 38.

[2] Minutes of Proceedings Inst. C.E., vol. cxxxviii. p. 1 *et seq.*

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slow for steels having critical points near ordinary temperatures, the air-valve is left open and the cooling is said to be hastened. If the hastened cooling is still too slow, as is sometimes the case, the specimens are simply exposed to the air; the cooling is then said to be rapid. The Leclercq-Forquignon furnace, though very convenient for cooling experiments, is not so well adapted for heating, because the pressure of the air may vary. In the nickel steels, however, it is not possible to neglect heating experiments. The following procedure is then adopted: A Mermet furnace heated by gas is lit, and a temperature of about 1,000° C. obtained. When the temperature becomes stationary, a small tube, containing the specimens and wrapped in an asbestos cloth, is introduced into the furnace tube. The metal is then heated rapidly and regularly, and the only observations to be made are the times of the passage of the luminous point over the divisions of the pyrometric scale. The results are shown in Tables I, II, and III, and in the curves of the Plate 2, referred to above. The critical points are indicated by the usual symbols: $Ar1$, $Ar2$, $Ar3$, during cooling; $Ac1$, $Ac2$, $Ac3$, during heating. The Tables suggest the following remarks:—

*Cooling.*—In the specimen A (0·27 per cent. of nickel) the three critical points are found with their maximums, respectively, between 775–765°, 715–695°, 645–635° C. In an ordinary steel of the same percentage of carbon (0·19), $Ar3$ would be about 800°, $Ar2$ between 750° and 700°, $Ar1$ about 660°. There is thus an appreciable lowering of the three critical points, due in great part to manganese, the effect of which is well known. For the same reason the point $Ar1$ is more clearly marked than in ordinary steels of equal hardness, the segregation of the ferrite being retarded by the manganese, and the proportion of perlite being greater at the instant of recalesence. The curve C (0·94 per cent. of nickel) is of the same type as A, with a new lowering of the three critical points between 755–745°, 710–685°, 625–615°. As the percentage of manganese is practically the same as in A (0·72 instead of 0·79), the lowering of the three points must be now attributed to the nickel. In the specimen E (3·82 per cent. of nickel), $Ar3$ and $Ar2$ merge in a double point $Ar3$–2, between 645–635°. $Ar1$ is lowered to 565–550°. In the specimen G (7·65 per cent. of nickel), the double point $Ar3$–2 is lowered still further, between 515-505°. A slight retardation, between 435–425°, might represent $Ar1$; but it is of slight importance and scarcely exceeds the possible experimental errors. Mr. Werth has found (and communicated to the Author) that in steels sufficiently

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TABLE I.—CRITICAL POINTS. COOLING FROM 1030° C.

| Specimen. | Method of Cooling. | Ar 3. | | | Ar 2. | | | Ar 1. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Begins about | Maximum between | Ends about | Begins about | Maximum between | Ends about | Begins about | Maximum between | Ends about |
| A | Normal | 795 | 775–765 | 750 | 750 | 715–695 | 660 | 660 | 645–635 | 630 |
| C | Normal | 775 | 755–745 | 730 | 730 | 710–685 | ? | 635 | 625–615 | 600 |
| E | Normal | | | | 660 | 645–635 | 580 | 580 | 565–550 | 530 |
| G | Normal | | | | 550 | 515–505 | 455 | .. | 435–425? | .. |
| J | Hastened | | | | 190 | 175–140 | ? | | | |
| J | Rapid | | | | 160 | 140–115 | ? | | | |
| K | Hastened | | | | 140 | 130–110 | ? | | | |
| K | Rapid | | | | 130 | 100– 65 | ? | | | |
| L | Rapid | | | | 40 | .. | ? | | | |
| M | .. | | | | .. | .. | .. | | | |
| N | Hastened | | | | 380 | 370–340 | 330 | | | |

TABLE II.—CRITICAL POINTS. COOLING FROM 1270° C.

| Specimen. | | Ar 3–2 | | | Ar 1. | | |
|---|---|---|---|---|---|---|---|
| | | Begins about | Maximum between | Ends about | Begins about | Maximum between | Ends about |
| C | Normal | 765 | 705–695 | 660 | 630 | 620-610 | 600 |
| E | Normal | 650 | 600–590 | 540 | 540 | 530–520 | 500 |
| G | Normal | 560 | 510–490 | .. | .. | 465–455? | 420 |

TABLE III.—CRITICAL POINTS. HEATING FROM ORDINARY TEMPERATURE.

| Specimens. | Ac 3. | | | Ac 2–1. | | |
|---|---|---|---|---|---|---|
| | Ends about | Maximum between | Begins about | Ends about | Maximum between | Begins about |
| A | 840 | 825–805 | 755 | 745 | 715–705 | 685 |
| C | 840 | 815–805 | 750 | 750 | 705–695 | 675 |
| E | 775 | 735–725 | 710 | 710 | 685-675 | 645 |
| G | 720 | 695–685 | 610 | | | |
| J | 625 | 605–595 | 565 | | | |
| K | 605 | 590–580 | 555 | | | |
| L | 580 | 570–550 | 520 | | | |

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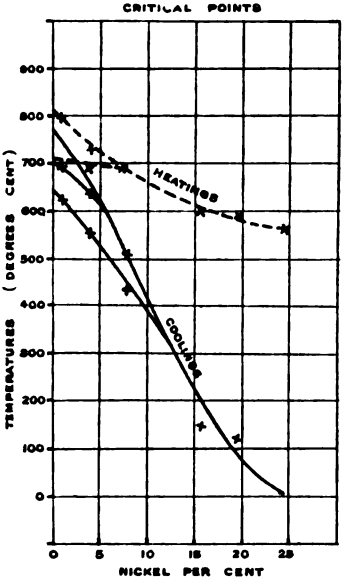
rich in nickel the carbon takes a special form resembling that of graphite. The point $Ar1$ may, therefore, be expected to disappear when the percentage of nickel is sufficiently great, without supposing it to merge, as in a triple point, with $Ar3$ and $Ar2$. In fact, in the specimens J (15·48), K (19·64), and L (24·51), there is only a single critical point. This critical point, in hastened cooling, falls between 170°–140° for J, between 130°–110° for K. For L, it commences at about 40° and is not finished at ordinary temperatures. The specimen M does not show any noticeable transformation. In N (49·65 per cent. of nickel), a slightly marked retardation is found between 370°–340°. Thus, when the percentage of nickel increases from nil to about 25 or 26 per cent., the three critical points successively unite and gradually get lowered from the normal position to the neighbourhood of ordinary temperatures. This is shown in *Fig. 1*, where the percentages of nickel are taken as abscissas, and the critical temperatures as ordinates. Even Dr. Hopkinson found[1] an alloy containing 25 per cent. of nickel, in which the transformation begins below zero. But this alloy probably contains more carbon than those of Mr. Hadfield.

*Fig. 1.*




The speed of cooling, within the limits of variation made by the Author, has an effect exactly similar to that observed in steels without nickel, but having the same percentage of carbon.

The influence of the initial temperature from which the cooling begins has been determined for a number of specimens. The curves, beginning at 1,270°, for the alloys C, E, and G, present the common characteristics of uniting $Ar3$ and $Ar2$, of delaying the transformations over a larger range of temperature, and of appreciably lowering the maximum.

Besides the critical points above described and identified, some of the cooling curves show small variations, of which the Author

[1] Proceedings of the Royal Society, 16th January, 1890.

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cannot suggest a satisfactory explanation. Several times during the experiments a sudden fall of temperature was observed, followed by a retardation. This phenomenon for the same steel was never repeated twice at the same temperature, and consequently tends to disappear on the average. But there are other retardations of more regular character which may have a real existence, although from their smallness they cannot be distinguished from possible experimental errors. In these doubtful cases the method recently described by Sir W. Roberts-Austen [1] could be applied with great advantage.

*Heating.*—The results are shown in Table III. Plate 2 [2] gives the curves for some specimens and, for alloys containing less than 25 per cent. of nickel, a resume is shown, *Fig. 1.* Referring to the curves, it is easy to see at a glance the general run of the phenomena. The curves of A and C are normal; the points Ac1 and Ac2 are merged, at least partially, in a double point Ac1–2, while the point Ac3 remains distinct. In the curve E the point Ac3 is lowered, and tends to merge with Ac1–2, which is also slightly lowered. From G (7·65 per cent. of nickel) to L (24·51 per cent. of nickel) the merging of the three points becomes and remains complete, with the qualification already made that the transformation represented by the symbol Ac1 in steels poor in nickel may not actually exist in steels rich in nickel. The multiple point gradually descends as the percentage of nickel increases.

Of course, no critical point is obtained by heating unless the cooling has been prolonged below the origin of the reciprocal point. If the cooling is interrupted before this origin and the metal is reheated, the heating curve is regular.

The heating curves for the alloys M (29·07 per cent. of nickel) and N (49·65 per cent. of nickel) show no retardation exceeding the possible limits of experimental error. This is to be expected for M, which shows no reciprocal point during cooling down to the ordinary temperature. It is otherwise with N, which might be expected to have a critical interval for heating as for cooling. This interval, in fact, exists, but the method of heating and cooling as applied by the Author is not sufficiently delicate for alloys containing more than 25 per cent. of nickel, these alloys having their transformations very feebly marked or spread over too large an interval of temperature to be clearly identified. These alloys should be examined by other methods; consequently

[1] Fifth Report to the Institution of Mechanical Engineers.
[2] See reference, p. 3.

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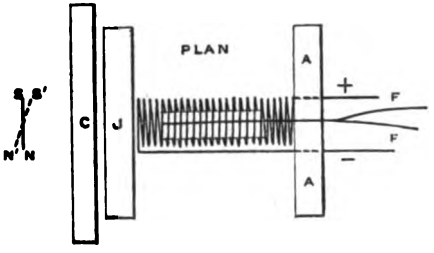
on diagram 1 only the alloys containing less than 25 per cent. nickel are represented.

*Comparison between Heatings and Coolings.—Fig. 1* admits of a comparison being easily made. The most striking fact is the gradual separation of the heating and cooling curves as the percentage of nickel increases from zero to 25 per cent. This was first shown by Messrs. Hopkinson and Le Chatelier.[1] This is also expressed by Mr. Guillaume[2] in saying that nickel steels below 25 per cent. are irreversible. Strictly speaking, they are not irreversible, except within a certain interval of temperature, increasing with the percentage of nickel; within that interval each alloy may exist in two extreme forms and in a series of intermediate forms. This is a point of primary importance in the history of nickel steel.

## Appearance and Disappearance of Magnetism.

These experiments were originally undertaken in order to throw light on points which the heating and cooling curves for alloys of over 25 per cent. left somewhat vague; they were afterwards extended to all the other specimens. Two bars of the same metal about 40 millimetres long and 6–7 millimetres side, containing between them the terminals of a Le Chatelier thermo-electric couple, are bound together by an asbestos cord, and are introduced into the centre of a solenoid about 70 millimetres long, made up of thirty turns of a platinum wire 1·6 millimetre diameter, *Fig. 2*. The whole is then placed in a small furnace heated by a Bunsen burner. The body of the furnace is not represented in the *Fig.* The right-hand side is made by two briquettes A A which allow the wires F F of the thermo-electric couple to pass between them; the left side is represented by the briquette J. A screen C with water circulation separates the furnace from the magnetic needle N S. The sensitiveness of the needle is regulated by a magnet, and the silk thread by which the needle is suspended supports a mirror

*Fig. 2.*




[1] Comptes rendus, vol. cx. p. 283, and vol. cxi. p. 454.

[2] Bulletin de la Société d'Encouragement, Mars 1898.

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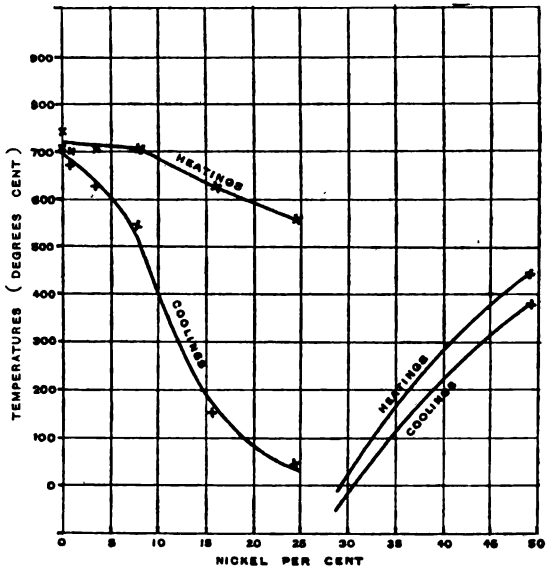
for magnifying the deviations. When the steel bars are magnetized the needle N S is deviated through a certain angle as at N′ S′, and the duplicate tangent of that angle, read in millimetres on a transparent divided scale, gives in arbitrary units a measure of the actual magnetism of the bar, the action due to the solenoid if traversed by a current being taken account of.

It is easy with this apparatus to follow the disappearance or appearance of the magnetism. The needle being at zero and everything being at rest, the current is turned on, the deviation is noted, the metal is introduced, the deviation is again noted, and

*Fig. 3.*




MAGNETIC TRANSFORMATION.

after having connected the thermo couple with the galvanometer, the gas is lit. Two observers, placed respectively before the scales of deviation and of temperature, mark on the same chronograph the moment of the passage of the luminous point over the divisions of the scales. At each instant, therefore, the deviation of the magnet and the corresponding temperatures during heating or cooling are obtained. At temperatures where the metal ceases to be magnetic the deviation is that due to the current only.

In the Author's experiments the current varies from day to day between 5·5 amperes and 6 amperes, giving a field of about 30 C.G.S. units. This field is too feeble to saturate the bars

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described, which weigh together about 20 grammes, while two bars of nickel produce a deviation at least equal to that which would be produced by two bars of iron of equal volume. Under these conditions the whole course of the magnetic change during the heating or cooling cannot be followed; it would be necessary to employ very much smaller bars. But the incipient appearance and the finishing disappearance of magnetism are registered with great delicacy.

The Author's experiments were of a preliminary character. While they lasted certain changes were made in the apparatus, and for this reason the curves for different specimens cannot be exactly compared. The temperatures, Plate 5, are not expressed in degrees Centigrade, but as arbitrary divisions of the pyrometric scale without corrections. The Author intended to compare the magnetic changes with the thermal transformations. The method of simultaneous observations permits of this comparison, independent of the absolute temperatures corresponding to the divisions of the scale of the pyrometer.

Plate 5 gives for each specimen examined the curves of magnetic moment during heating from the ordinary temperatures and during the subsequent cooling, together with the usual heating and cooling curves when they are useful for the purpose intended. The left horizontal part of the curves of magnetic moment represent the deviation due to the magnetizing solenoid alone during the portion of the experiment when the metal is non-magnetic.

For the alloy A the cooling curve does not show the point $Ar3$, because the previous heating had not been carried as far as the origin of $Ac3$. The appearance of the magnetism during cooling is seen to begin with $Ar2$, and its disappearance during heating finishes with $Ac1$–$2$. The same fact is more clearly seen in the curve of the alloy C, which possesses its point $Ar3$, and is therefore complete. These first results confirm the identification of the magnetic transformation with the point A2. The Author has already found this to be the case for a mild steel without nickel and for a silicon steel. The experiments of Ledeboer[1] and of Madame Curie[2] lead to the same conclusion. The Author was wrong in his former opinion that the magnetic transformation coincided with A3, the results of Hopkinson, on which the opinion was based, not being comparable with the Author's on account of the different methods used for measuring high temperatures.

[1] Comptes rendus, vol. cvi. p. 129 (9th January, 1889).
[2] Bulletin de la Société d'Encouragement, January, 1898.

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The beginning of the appearance or the end of the disappearance of the magnetism therefore marks exactly the superior limit of A2. We have, therefore, a means of recognizing A2, even when this is confounded with other critical points in the thermal curves. Thus in the alloy E (3·82 per cent. of nickel), when the points A3 and A2 appear to be merged completely during cooling, and partially during heating, it is seen that the appearance as well as the disappearance of the magnetism coincides with the maximum and not with the superior limit of the double points; it may, therefore, be deduced that, in spite of the apparent confusion, the transformation $Ar3$ is fairly well advanced before the transformation $Ar2$ begins. In the specimen G (7·65 per cent. of nickel), and in alloys richer in nickel, the appearance and disappearance of the magnetism agrees closely with the superior limit of the double points; the points A3 and A2 are in these cases exactly coincident.

In the alloys richer in nickel new phenomena are observed; the return of the magnetism takes place at two distinct periods. The first phase begins at a temperature practically constant between 510° and 550.° It is slightly marked in J (15·48 per cent. of nickel), and is more clearly marked as the percentage of nickel increases. This first phase is reversible, in other words the curves of magnetic moment during heating and cooling are nearly coincident; it is progressive, *i.e.*, the magnetism increases as the temperature is lowered, and diminishes as the temperature is raised. These phenomena have been, up to the present, only observed in the Hadfield nickel-steels. The Author has found but traces of the phenomenon in similar French steels, and is quite in the dark as to the cause. Whatever be the explanation, it is to these phenomena that the alloy M (29·07 per cent. of nickel) owes its property of being slightly magnetic at ordinary temperatures. In this alloy the principal phase begins below zero.

In what follows, when the Author speaks of the appearance or disappearance of magnetism, reference is made to this principal phase. All the curves, with the exception of that of E, show that the magnetic moment of a steel (the magnetising current remaining constant) is slightly greater at the end of cooling than at the beginning of heating. The difference, as a first approximation, appears to be equal to the remanent magnetism in the bars when the current is stopped.

The curves of Plate 5 give evidence of the irreversibility of steels containing less than 25 per cent. of nickel. Their irreversibility is measured by the difference of temperature between

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the appearance and disappearance of the magnetism. On the other hand, in the alloy N (49·65 per cent. of nickel) the principal magnetic phase is reversible, as has already been shown by Mr. Guillaume. The difference of about 50° shown by the specimen N is probably exaggerated by the comparatively great speeds of heating and cooling in the region of the transformation.

Table IV shows the temperatures of appearance and disappearance

TABLE IV.

| Specimens. | Disappearance of Magnetism. | Appearance of Magnetism. | Specimens. | Disappearance of Magnetism. | Appearance of Magnetism. |
|---|---|---|---|---|---|
| | ° | ° | | ° | ° |
| A | 735 | 715 | J | 623 | 145 |
| C | 700 | 675 | L | 558 | 40 |
| E | 710 | 628 | M | Below zero | Below zero |
| G | 710 | 530 | N | 445 | 375 |

of magnetism of all the alloys examined. *Fig. 3* shows the same results graphically. The left descending branch, which has already appeared in *Fig. 1*, may now be joined to the right ascending branch, that of reversible steels. The few figures quoted above would appear to be insufficient for drawing this branch with accuracy; but the experiments of Mr. Guillaume, which were very complete in the region under consideration, permit of the curve being drawn with practical exactitude.

With regard to the two portions of the cooling curve, it would appear that these lines ought to intersect about 29 per cent. of nickel, and that the minimum indicates the existence of a eutectic alloy. But this would be a highly speculative interpretation. There are certain steels of approximately this composition which are not transformed even in liquid air. There is no point of the horizontal line which would correspond to the hypothesis of a eutectic; and lastly, the curve of the magnetic transformation during heating has an enormous gap. It is, therefore, difficult to interpret the passage from irreversible to reversible steels. It is not less difficult to explain the signification of the ascending branch between 29 per cent. and 50 per cent. of nickel. As already remarked, steels of this composition give only a feeble disengagement of heat at the critical points. Even taking account of the fact pointed out by Messrs. Guillaume and Dumont[1] that

[1] Comptes rendus, vol. cxxvi. p. 741.



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these transformations extend over a large interval of temperature, the liberation of heat does not appear to represent the sum of the points $Ar3$ and $Ar2$ corresponding to the quantity of iron present. As the point $Ar2$ is characteristic of the magnetic transformation it may be supposed either that the point $Ar3$ disappears above 29 per cent. of nickel, or that it is masked by other superposed endothermic phenomena. They certainly present difficult problems for solution.

## Microstructure.

The alloys of iron and nickel may be divided into three groups :—

(1) From A to G (7·65 per cent. of nickel) inclusive, the structure resembles that of ordinary steels without nickel. But the grains of ferrite are, other conditions being equal, of smaller dimensions, and have less tendency to become larger under the influence of high temperatures, thus giving a fibrous appearance to a fracture.

(2) The second group, comprising J, K, and L, extends up to steels with about 25 per cent. of nickel. The usual methods of etching show a structure of straight parallel fibrous bundles in three principal directions (crystallographically they may be of the octahedral form, Fig. 1, Plate 6, 600 diameters magnification). The carbon, at least when in small quantities, is not in the form of segregated carbide. The characteristics are similar to those of martensite, a constituent of hardened carbon-steels. This similarity is more remarkable since the steels of this group are relatively self-hardening.

(3) The third group includes the alloys non-magnetic at ordinary temperatures, and all alloys richer in nickel up to 98·5 per cent. of nickel.[1] The usual methods of etching ordinary steels do not give good results. It is best to employ hydrochloric acid or ammonium chloride, the metal being connected to the positive pole of a bichromate cell. The structure is purely crystalline, Figs. 2, 3, and 4, Plate 6. The crystals become larger and more clearly marked after annealing from a high temperature, Fig. 2, magnification 25 diameters. They may be octahedrons, but as they mutually arrest each other in their

[1] With the same percentage of nickel (24·80) an alloy of 0·16 per cent. of carbon is magnetic, an alloy of 0·65 per cent. of carbon is non-magnetic at ordinary temperatures, after cooling under the same conditions. As regards structure, the first of these alloys belongs to the second group, the second alloy to the third.

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growth, the determination cannot be certain. Whatever be the crystallographic system to which they belong, the prepared specimens are very characteristic, Figs. 3 and 4, magnification 600 diameters, and suggest the structure of pure iron above the point A 3, as shown by Mr. Saniter by means of fused calcium chloride.[1] The alloys of this group are usually riddled with small holes after etching, the cause being unknown to the Author.

All nickel steels possess another interesting property, that of easily becoming schistous by forging. The Author has already noted similar facts for ordinary steels, but these not being homogeneous, the elements of the structure, of unequal hardness, are unequally drawn by working. In nickel-steels the laminar structure is superposed on the structures already described. In the metals of the second and third groups it is completely independent, cutting the forms of the crystals. It is shown in all methods of etching by the formation of bands alternately more or less attacked, which allow the deformations due to the forging or rolling to be seen, Fig. 4. When the alloys of the second group are tempered after heating to dull red below the critical point Ac 3–2, the forms of the martensite become less distinct, exactly as with tempered carbon steel.

## Magnetic Properties.

Some years ago, the Author suggested[2] that the total magnetism up to saturation of any steel might be a measure of the quantity of $\alpha$ iron contained in that steel, and that the residual magnetism, other things being equal, might be a fraction of the total magnetism, which would be greater the smaller the proportion of $\alpha$ iron. It follows that if the hardening carbon, the manganese or the nickel alloyed with the iron increased continuously, the total magnetism should decrease from its maximum to zero, while the remanent magnetism should increase from zero to its maximum, and then decrease to zero.

The Hadfield series of nickel steels was admirably adapted for a verification of these ideas.

The total magnetism was determined by observing the tractive force. Each of the bars, after reheating to cherry-red, followed by cooling on a brick, was placed against one of the poles of a

[1] Journal of the Iron and Steel Institute, 1898, part 1, p. 206, Plates xxii. to xxv.

[2] Philosophical Magazine, June, 1890, p. 511.



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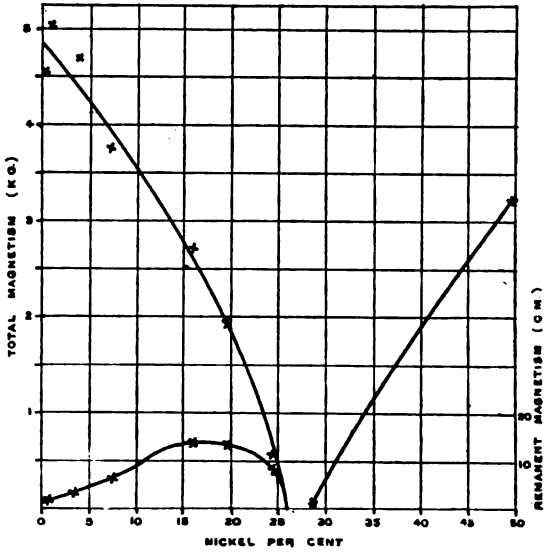
horse-shoe electro-magnet traversed by a current of 5·7 amperes, and the weight necessary for separation was observed. The

TABLE V.

| Specimens. | | Dimensions of Bars. | | Magnetism. | |
|---|---|---|---|---|---|
| | Percentage of Nickel. | Weight. | Length. | Total. Tractive Force. | Remanent. Deviation. |
| | | Grams. | Millimetres. | Kilograms. | Millimetres. |
| A | 0 27 | 10·285 | 38·0 | 4·550 | 14·7 |
| C | 0·94 | 11·230 | 38 3 | 5·050 | 14·9 |
| E | 3·82 | 9·795 | 37·6 | 4·675 | 25·0 |
| G | 7·65 | 10·770 | 37·7 | 3·725 | 60·0 |
| J | 15·48 | 10·670 | 36·7 | 2·725 | 135·6 |
| K | 19·64 | 11·285 | 38·5 | 1·950 | 124·5 |
| L | 24·51 | 12·345 | 37·6 | 0·450 | 112·3 |
| M | 29·07 | 11·115 | 36·5 | 0·050 | 2·5 |
| N | 49·65 | 12·220 | 37·5 | 3·225 | 4·9 |

*Fig. 4.*




TOTAL AND REMANENT MAGNETISM.

method is rough, but is sufficient to follow the general nature of the variation.

To measure the residual magnetism, the apparatus above described for the appearance and disappearance of magnetism was

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used. Each bar, after being placed on the pole of the electromagnet and magnetised by six successive passages of the current of 5·7 amperes, was placed at a fixed distance from the magnetic needle, and the deviation on the tangent scale was observed. The figures obtained are not absolute, but they can be compared one with the other. Care was taken that the bars were magnetised almost to saturation. The results are shown in Table V, and in the curves, *Fig. 4*.

For irreversible steels, the total magnetism is gradually lowered and becomes nearly zero as the percentage of nickel increases from zero to 29 per cent. At the same time the remanent magnetism begins from a relative minimum, attains a maximum in the alloy J (15·48 per cent. of nickel), then slowly diminishes, and evidently becomes zero in the non-magnetic alloys.

These facts agree with the suggested theory. If the relative minimum of the alloy A has a value appreciably great, it is because the alloy contains 0·27 per cent. of nickel, 0·19 per cent. of carbon, and 0·79 per cent. of manganese (quantities which are far from being negligible), and that the cooling in air of a bar 6 millimetres to 7 millimetres square may produce a slight hardening. From M (29·07 per cent. of nickel) the total magnetism again increases rapidly with the percentage of nickel. In the alloy N (49·65 per cent. of nickel) it is perhaps greater than the calculated magnetism due to a mixture of pure iron and nickel. Hopkinson has already noted the same phenomenon in a nickel iron alloy containing 73 per cent. or 75 per cent. of nickel. In the reversible steels the residual magnetism is so small that, on the scale chosen, the curve sensibly coincides with the axis of abscissae.

The curve of total magnetism, *Fig. 4*, is exactly similar in character to the curve of the critical points of magnetic transformation during cooling, *Fig. 3*. As the mechanical properties of steels bear some relation to their magnetic properties, and the magnetic properties are related to the temperatures of the critical points, the mechanical properties are therefore functions of the temperatures of the critical points. It is to be noticed that the absolute maximum of the residual magnetism in the series of irreversible alloys coincides with the maximum hardness.[2]

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[1] Discussion of Mr. Parshall's Paper, "Magnetic Data of Iron and Steel." Minutes of Proceedings Inst. C.E., vol. cxxvi., p. 71.

[2] See the quoted Papers by Mr. Guillaume and that by Mr. E. Dumont, "Researches on the Magnetic Properties of Nickel-Steels," Extrait des Archives des Sciences Physiques et naturelles, Geneva, 1898, published by Rey et Malavallon.

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### Tempering of the Self-Hardened Alloys.

It is well known that certain nickel-iron alloys, especially those containing about 14 per cent. to 15 per cent. of nickel, after slow or rapid cooling from cherry-red, possess somewhat great hardness. Mr. Werth has found that this hardness, like that of hardened carbon steels, may be diminished at will by tempering to a temperature less than that of the critical point of heating. This property shows that the transformation of the alloys considered remains incomplete during cooling from cherry-red, or in general from a temperature above that of Ac 3–2. This fact is one of great importance, since it allows of the metal being softened to be machined, and of being hardened before using it. It has formed the subject of a patent by the Société de Denain et Anzin.

The measurement of the remanent magnetism of short bars gives a convenient method of studying the influence of the thermal treatment. The Author has made some experiments in this direction on the alloys J (15·48 per cent. of nickel) and K (19·64 per cent. of nickel). These alloys were subjected to a series of successive heatings to temperatures progressively diminishing to 634° C. Hardened by this last treatment, they were then subjected to another series of heatings to temperatures progressively increasing, until the initial condition was again

Table VI.

| | J (15·48 per cent. Ni). | | | K (19·64 per cent. Ni). | | |
|---|---|---|---|---|---|---|
| | Remanent Magnetism. | | | Remanent Magnetism. | | |
| | Before Magnetization. | Immediately after Magnetization. | 15 minutes after Magnetization. | Before Magnetization. | Immediately after Magnetization. | 15 minutes after Magnetization. |
| | Millimetres. | Millimetres. | Millimetres. | Millimetres. | Millimetres. | Millimetres. |
| Heated to 837 | Trace | 132·0 | 118·5 | Trace | 121·0 | 106·0 |
| ,, 770 | Trace | 141·0 | 126·5 | Trace | 126·6 | 114·5 |
| ,, 710 | Trace | 146·0 | 127·9 | Trace | 131·5 | 118·4 |
| ,, 634 | Trace | 153·4 | 141·5 | Trace | 166·0 | 150·6 |
| Remagnetized | .. | 155·9 | .. | .. | 169·0 | .. |
| Heated to 105 | 121·0 | 154·8 | 152·0 | 139·6 | 168·0 | 163·7 |
| ,, 214 | ? | 139·3 | 138·9 | 116·5 | 150·9 | 150·0 |
| ,, 303 | 76·5 | 123·7 | 123·3 | 93·0 | 132·3 | 132·5 |
| ,, 370 | 57·8 | 98·1 | 98·0 | 70·7 | 104·9 | 104·9 |
| ,, 415 | 38·0 | 78·0 | 78·0 | 46·4 | 82·9 | 82·9 |
| ,, 475 | 25·9 | 64·0 | 64·0 | 30·0 | 72·1 | 72·1 |
| ,, 514 | 20·0 | 64·8 | 64·5 | 27·0 | 78·4 | 78·0 |
| ,, 565 | 6·8 | 149·0 | 136·0 | 1·0 | 181·0 | 171·0 |
| ,, 603 | Trace | 164·0 | 149·8 | Trace | 175·0 | 165·5 |

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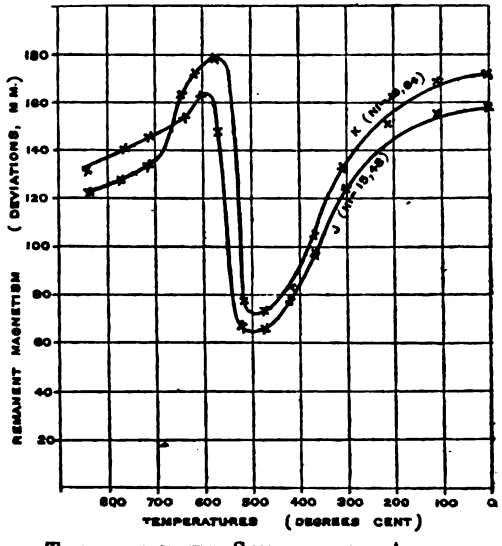
reached and the cycle closed. The heating took place in the apparatus used in the researches on the temperature of magnetic transformation. When the desired temperature was obtained, the gas was extinguished and replaced by a current of cold air until the temperature fell to 60°. The bars were then removed from the furnace and allowed to cool for ten minutes. The residual magnetism was measured, the bars were again magnetised by the electro-magnet traversed by a current of 5·7 amperes, and the remanent magnetism was measured immediately, and again at the end of fifteen minutes. The measurements were made, as

*Fig. 5.*




TEMPERING OF THE SELF-HARDENED ALLOYS.

in the other experiments, in arbitrary units. The results are shown in Table VI and in the curves, *Fig. 5*. A glance at these curves shows the effect of the successive heatings, the softening and the hardening being clearly shown. It should be added that the results might be considerably modified by varying the speed of cooling and heating. Lastly, it should be remembered that the magnetism is much more stable in tempered than in annealed bars. The above experiments clearly show that in ordinary working these nickel-steel alloys must be very carefully handled.

The Paper is accompanied by two drawings and four photographs, from which Plates 5 and 6 and the Figures in the text have been prepared.

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*(Paper No. 3060.)*

# "Sluices of the Betwa Canal-Head and Weir."

By ROBERT MACALISTER, M. Inst. C.E.

THE calculated flood-discharge of the River Betwa, in India, is 750,000 cubic feet per second. The weir across the river at Paricha, near Jhansi, is 4,000 feet long with a maximum height of 60 feet, and has four sluices 12 feet by 6 feet, with a floor at R.L. 608. Each of the openings is provided with an iron gate on the up-stream, and a drop-gate on the down-stream side (*Figs. 1*). The object of the latter is to close the opening in the event of the iron gate or gear being deranged. The iron gate is 12 feet 3 inches by 6 feet 9 inches by $8\frac{3}{4}$ inches. It has a framework of channel-bars, 8 inches by 3 inches by $\frac{5}{8}$ inch, the horizontal beams being arranged so that there may be equal pressure on each. The vertical channels at the sides extend 1 foot 6 inches above the top of the gate to provide an attachment for the lifting gear. The gate is covered in front with $\frac{3}{8}$-inch plates, and on the back has two vertical plates 12 inches by $\frac{3}{8}$ inch. The horizontal beams are designed for pressure due to a head of $31\frac{1}{2}$ feet.

Manual labour is the power employed for lifting. Two box girders at R.L. 648 rest on cast-iron bed-plates, bolted down to the masonry to resist the upward thrust in closing the gate. On these girders is secured a cast-iron thrust-block, which is fitted with a gun-metal nut, having thrust collars on the outside. To this nut the capstan head is fixed. The screw, which is of wrought iron $4\frac{3}{4}$ inches diameter, has a square thread, and is provided with a flat end for attachment to the cross-beam below. The ends of this cross-beam are attached to the upper ends of two angle-bar pillars within the grooves. The lower ends of these pillars are attached to the projecting channel-irons on the sides of the gates. The pillars are strengthened by diagonal bracing. The gearing is designed for a pressure due to a $21\frac{1}{2}$-foot mean depth of water.

The drop-gate is of sâl, one of the heaviest and strongest timbers procurable. It is built up of a series of 8-inch square balks laid over one another and bolted together by four $1\frac{1}{2}$-inch bolts between

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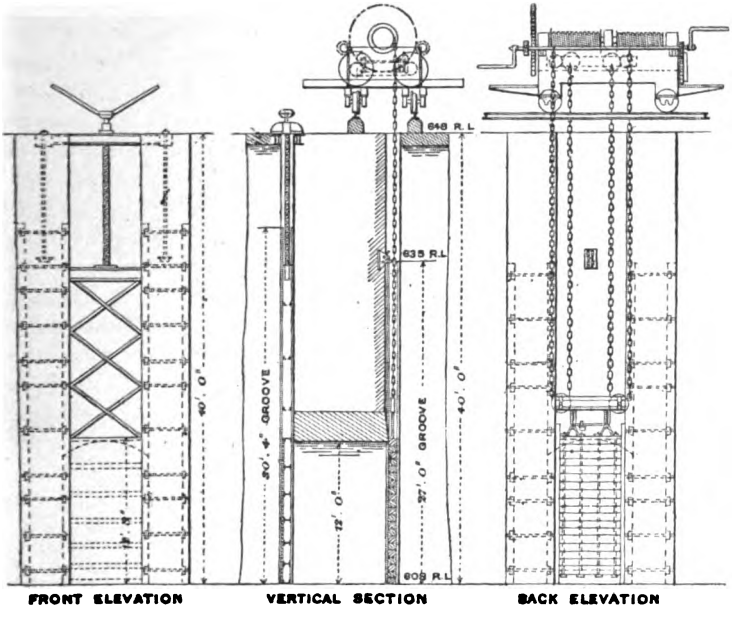
two angle-bars 8 inches by 3 inches by $\frac{3}{8}$ inch on the top and bottom. The bearing-surfaces of the gate have angle-bars 8 inches by 3 inches by $\frac{3}{8}$ inch, and on the bottom a wearing-block of timber is attached which can be renewed without disturbing the fixed portion of the gate. The gate is ordinarily suspended from the drop clip at R.L. 635. After being dropped it may be necessary to raise it under a 31½-foot head, and for this purpose a 25-ton travelling crab is provided. The crab has a grappling beam attached, on the under side of which are two projecting forks

*Figs. 1.*




Scale, $\frac{1}{16}$ inch = 1 foot.

GATES FOR WEIR SLUICES.

fitted with pawls, which, on the beam being lowered, allow the forks to pass two Λ-shaped bars attached to the top of the gate, and on the beam being reversed the gate is raised. The chains are wound on two grooved barrels, and the crab is free to travel longitudinally to either side to accommodate itself to the position of the chains on the barrel. Cast-iron grooves are built into the masonry and are bolted together in pairs. The bearing-surfaces of these are planed.

The canal-head has five bays, each having two openings of

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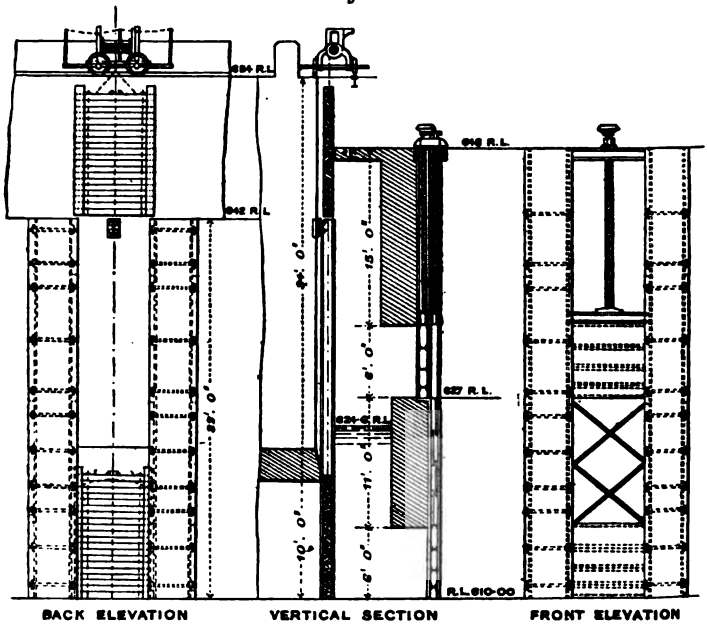
6 feet by 6 feet for the regulating sluices on the up-stream side, and one opening 10 feet by 6 feet for a wooden drop-gate on the down-stream side. The bottom of the lower opening is at R.L. 610, and that of the upper opening at R.L. 627. The reason for having a set of gates at a higher level is that, during the rainy season, a small supply of water only is required for the irrigation of the rice crops; and this can be more easily taken off under a less head through the upper sluices at this season, when there is a full supply in the river.

*Figs. 2.*




Scale, $\frac{1}{12}$ inch = 1 foot.

GATES FOR REGULATING SLUICES.

The sluices, *Figs. 2*, are of the same general construction, and are similarly worked by screws. The upper and lower gates are of exactly the same dimensions, so that they may be interchangeable. The lower gate is in front of the upper one, and they are worked by independent screws of the same dimensions as those for the weir sluices. The two gates are never worked simultaneously. The bracing of the frame of the lower gate is stopped short in front of the upper gate to provide a clear opening.

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The drop-gate, *Figs.* 2, is of the same construction as that for the weir. A less powerful crab is provided, as it is not necessary to raise this gate under such high pressure. The gate is ordinarily suspended from a drop clip at R.L. 642. In the event of the fall being interrupted, provision is made by leaving a slot in the piers to open communication between the bays, to allow of another gate being traversed to this bay, and dropped on the top of the first to ram it down.

The whole of the work was designed by and constructed under the supervision of the Author at the Canal Foundry and Workshops, Public Works Department, Roorkee.

The Paper is accompanied by four photo-prints, from which the Figures in the text have been prepared.

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(*Paper 3062.*)

# Irrigation Works in the Jeypore State, Rajputana, India.

By Charles Egremont Stotherd, Assoc. M. Inst. C.E.

The Paper gives a short description of some of the principal irrigation works carried out in the Jeypore State during the last twenty years, showing the different methods which were adopted, and the results attained. The works were all carried out under the superintendence of Colonel S. S. Jacob, C.I.E., Assoc. Inst. C.E., whose services were lent to the Jeypore State by the Imperial Government in 1867, and who has been engaged there since that time.

It is not suggested that the design of the works is the most economical that could have been adopted in each particular case, as in many instances a large margin of safety has purposely been provided, the works being all carried out under the supervision of a single officer, whose multifarious duties precluded the possibility of his constant residence on the work. The methods adopted were also in some cases tentative, but up to the present all have met with a successful result. All the works were constructed entirely by local native agency.

The Jeypore State covers an area of 14,527 square miles, and lies between 25° 43′ and 28° 23′ north latitude, and 74° 50′ and 77° 18′ east longitude. The general character of the country is level and open; but there are numerous hilly tracts and ridges with isolated peaks rising several hundred feet above the surrounding plain, constituting a continuation of the Aravali range of hills. They are composed chiefly of quartzite rocks, probably belonging to a period anterior to the old red sandstone of Great Britain, but as they contain no fossils, their exact age is doubtful. In the north these hills contain valuable mines of copper, iron, and cobalt, but for lack of transport and fuel these are not worked at the present day. In the west of the State is the Sambher Salt Lake, where excellent salt is manufactured by the Imperial Revenue Department. A good variety of red sandstone is quarried

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in the east of the State, also valuable red and white marbles, while at the town of Bhankri slabs of mica-schist up to 30 feet in length are readily procurable for roofing purposes.

The nature of the soil in the plains varies from black cotton soil in the south and south-west to the sands of Sheikhawati on the borders of the Bickaneer desert in the north. The centre of the State is an elevated table-land, about 1,400 feet above the sea-level, and falling rapidly towards the east and south, where it is only some 700 feet high.

The average yearly rainfall of the country varies from 35 inches in the extreme south to about 20 inches in the north. The whole of this quantity, with the exception of about 2 inches, falls between the middle of June and the middle of September. The yearly rainfall, however, is extremely variable. Thus, at Jeypore City, during 1892, 55·27 inches of rain fell, while in 1877 the fall was only 9 inches; and in the present year 14·10 inches has been recorded—the average for the whole period being 25·78 inches. In the north, on the borders of the Bickaneer desert, the rainfall is still more precarious.

There are several large rivers and streams in the State, but these, with the exception of the Banas, which drains an area of some 14,000 square miles, are mostly dry, except during the monsoon months—June to September.

It is, therefore, of the highest importance to impound, during the monsoon, all the water that can possibly be stored, in order to utilise it for irrigation purposes during the ensuing months, also to provide against the droughts which appear to recur in periods, every fifth, ninth, or nineteenth year, by storing the surplus water of a good year and utilising it in a bad one.

## Moran Lake.

This reservoir is an instance of an earthen dam in which a core-wall of masonry has been subsequently inserted. It was commenced in 1877 and completed in 1878, and was carried out under the superintendence of the late Mr. T. W. Miles, M. Inst. C.E., who at that time was associated with Colonel Jacob in the Public Works Department of the Jeypore State. It is formed by closing up two gaps in a rocky chain of hills with dams, at first consisting solely of earth. The dams are 3,380 feet in total length, the inner slope being 3 to 1 and reveted with stone, the outer slope 2 to 1, and the top width 20 feet. The drainage area is about 35 square miles, consisting of bare rocky hills; consequently a good per-

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centage of the rainfall is secured. When full, the area of the lake is 2 square miles, the greatest depth of water being 28 feet, and the capacity 456 million cubic feet. The total expenditure on the work up to December 1895 was Rs.1,60,365, and up to date it has yielded an estimated average revenue in water rate and share of produce of Rs.24,005 per annum, or 14·96 per cent. per annum. The canals and distributaries aggregate about 56 miles in length.

On 25th July, 1882, a heavy fall of rain occurred, and water flowed over the three waste weirs, 421 feet in total length, to a maximum depth of 2 feet, from 6 A.M. to midnight.

The Babul trees planted on the slopes of the embankment were afterwards cut away and their roots removed, as they were found to be dangerous in the rainy season; the movement of the trees by the wind having a tendency to loosen the soil and to allow water to creep along the roots. The reservoir constantly overflows, and it is only on account of the submersion of property which would occur that has prevented its being raised 2 or 3 feet. In 1886 a masonry core-wall was inserted into the bank where it crosses the bed of the stream, a length of 605 feet, and in 1892 a further length of 900 feet of masonry core-wall was built. The reason why masonry core-walls are not always adopted is, that it is advisable to keep the original cost of these works as low as possible. In many cases experience has proved that masonry core-walls are not necessary—where there is any doubt, and no fear of the consequences of a breach, they have been omitted, and added when the necessity has arisen.

With black cotton soil, or soil composed of earth mixed with kunkur nodules, the core-walls are almost indispensable, as these soils gutter very badly, and, though as hard as rock in the dry season, become very soft during the rains. Failure in embankments consisting solely of this earth frequently results from the holes which animals make during the dry season. An instance is recorded of a leak through one of these holes gradually enlarging till a tunnel 10 or 12 feet high was formed in the embankment, which remained standing after the whole of the water had escaped from the reservoir. It is the practice, therefore, to have such holes carefully stopped each year before the commencement of the rains.

The average cost of the uncoursed rubble masonry, such as is built in these core-walls, is from 10 to 15 rupees per hundred cubic feet, the rate varying of course with the proximity of the materials.

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## Kalegh Reservoir.

This reservoir has an embankment composed entirely of sand, but abutting on to rock at one end. It was commenced in 1880 and completed on 11th October, 1882, and is, financially speaking, the most paying irrigation work in the State, having cost up to December 1895 only Rs.2,59,087, while the revenue realised averages Rs.40,788 annually, a return of 15·75 per cent. per annum. The capital cost of the work was paid off within eight years of the date of its completion.

The project consists of impounding the waters of the River Bandi at a point where its course passes between the rocky spur of Kalegh Hill and some sand hills to the north. The river at this point was 305 feet wide. The embankment is composed entirely of sand, the inner slope is 4 to 1, and the outer slope 3 to 1, the width at the top being 20 feet. At the point at which the embankment abuts on to the rock a core-wall of masonry, 30 feet long and 2 feet thick, was built into the dam to prevent water creeping along the face of the rock and endangering the sand dam. Rubble at the toe of the outer slope 10 feet wide and 3 feet high prevents any erosion of the outer slope. These measures have been completely successful. The length of the dam is 730 feet at the top and 305 feet at the bottom, and the height 50 feet. The greatest depth of water impounded is 30 feet, of which 25 feet is available for irrigation, the remaining 5 feet being allowed for any silting up which may subsequently take place.

The drainage area above the bank is 227 square miles, and consists of a level sandy plain, except at the source of the river, which is in rocky hills. One feature of the work is the waste weir, which is cut out of the rocky spur of Kalegh Hill, and is only 100 feet long. This has been found more than sufficient for all contingencies, because the area of the lake at the 30-feet contour is no less than 1,540 acres, and the very sandy nature of the catchment area prevents much run-off at any time.

The total capacity of the tank is 578¾ million cubic feet. Two cast-iron outlet sluices, each 3 feet diameter, are provided in the centre of the waste weir.

A well is provided in front of these outlet sluices, in which a 3-feet sluice is placed. This is kept open, but can be closed to enable the other two outlet sluices to be inspected in case of necessity. Subsequent experience shows that sluices of 2 feet diameter are sufficiently large for all purposes. The stone

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excavated from the spur to form the overflow weir was spread over the inner face of the dam to prevent any scour of this face.

The canal starts about 6 miles below the dam, where a masonry weir, 12 feet high, founded on rock, has been built across the course of the Bandi, to raise the level of the water to the irrigation canal. The water from the reservoir, controlled by the sluices, runs down the course of the river, and is diverted by the weir into the canals and distributaries as it is required. Owing to the hilly or broken character of the ground no irrigation is possible on either bank of the river for the first 7 or 8 miles. The sluices to supply the canal consist of five openings, each 4 feet square, founded on rock. Scouring sluices are also provided in the weir to keep the head works free from silt. The canals consist of 55 miles of main canal, and 118 miles of distributaries.

The first year's rainfall impounded was that of 1881, before the completion of the work, when the reservoir filled to within 2 feet of the waste weir level. The rainfall of this year, June to September, was 18 inches. In 1882 only 13 inches fell during this period, but the reservoir again filled to the same height. In 1883 the reservoir filled 23½ feet, *i.e.*, to 6½ feet below waste weir level, with a rainfall of 20 inches. In 1884 the reservoir filled for the first time, 6 inches of water also passed over the waste weir, the rainfall for the year being 21·79 inches. In 1885 discharge over the waste weir from 21st August to 25th September occurred to a maximum depth of 2 feet 1 inch. In 1886 the water level in the reservoir was raised 1 foot by building a small masonry wall on the overflow weir. By this means its capacity was increased by 74 million cubic feet. In 1887 the depth of water over the waste weir reached 2 feet 3 inches, the greatest depth recorded to date.

### Tori Reservoir.

This is the largest reservoir in the Jeypore State, covering when full an area of 6·35 square miles. With the exception of the Jai Samand in Udepur territory, it is also the largest artificial lake at present existing in Rajputana. A river, known as the Sohadra, which has its source in the Ajmere district, passes over a rocky bed at the site of the dam near the village of Tori, south of the hill of that name. Exclusive of areas cut off by smaller irrigation schemes, the area of catchment above the site of the dam is about 320 square miles. It is hilly at the sources of the river, but chiefly consists of a wide cotton soil plain.

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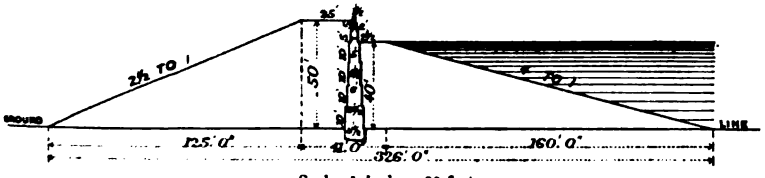
The average rainfall for the district, calculated over 14 years, is 21·84 inches.

The length of the bank is 6,400 feet, the greatest depth of water 40 feet, and total capacity of the tank 1,750 million cubic feet, capable of irrigating 43,750 Jeypore Bighas, or 14,583 acres. With the exception of 1,500 feet at the north end of the dam, a core-wall has been built in the bank which forms, above the high-water line, a retaining wall for the earth (*Fig. 1*).

A level berm, 10 feet wide, is made at high-water level to prevent the earth being cut away and the core-wall exposed. The inner slope of the dam is 4 to 1, the outer 2½ to 1. The inner slope is protected by a layer of kunkur and stone, 1 foot thick, to prevent waste guttering the slope.

The waste weir is 1,000 feet long, of which 700 feet is built up, the remainder being on the natural surface of the ground; it is situated at the south end of the dam. The disadvantage of

*Fig. 1.*




Scale, 1 inch = 80 feet.

CROSS-SECTION OF THE TORI DAM.

making the waste weir at one end of a dam is that any overflow has to cross the irrigation canal on its way back to the river. If the overflow is great, as in this case, it may cause damage to the canal and necessitate protective works—to pass off the surplus water—either under or above the canal. The masonry core-wall is founded on rock when possible, and where no rock existed the foundations were carried down 8 feet below the surface of the ground to a substratum of sound earth, and the wall built on a bed of concrete, well consolidated. The outlet channel to the sluices has been cut in solid rock to points in the dam well above the original course of the river; the object being to secure a site where the height of the bank is small, and the foundations good, also to enable the canals to be conveniently led away. This course is always adopted to diminish the risk of the failure of the dam at the sluices, through water creeping along between the masonry and earthwork, or beneath the foundations.

There are two main canals, 47½ miles long, led away from the



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dam north and south of the course of the river, the breadth at formation decreasing from 20 feet to 12 feet, and side slopes 1 to 1. The irrigation ducts at present aggregate 67·32 miles. Where cross drainage meets the canals core-walls or waste weirs have been built, so as to dam them up and divert their waters through the canals into adjacent reservoirs, or, if the volume of water is very great, to allow its free passage over the canal.

The total expenditure up to 31st December 1895 has been Rs.5,77,753; the average annual revenue now collected being Rs.48,299, giving an average return of 8·36 per cent. on the total cost of the work.

The water from the outlet sluices before reaching the canals passes through a turbine, which is used for grinding corn.

The work was commenced in May 1882 and completed October 1885. In 1883 the work was proceeded with, a gap being left at the river to provide for the escape of its flood waters.

In the construction of the work, Decauville's portable railway 16-inch gauge was used, with great advantage, for the earthwork and transport of material.

In addition to the ordinary sluice valves, grooves have been provided in the cut stonework of the wells in front of each set of sluices, into which planks can be fitted to permit access to the valves should they ever get out of order. In 1885 the first year's rainfall was impounded; a fall of 6·5 inches on the 25th of August filled the reservoir to within 3 feet of waste-weir level. In 1887 the reservoir filled, and for about 40 days 11 inches of water ran over the waste weir. The monsoon rainfall over the catchment area in this year was 32·50 inches. In 1888 there was a very heavy fall of rain, amounting to 8·45 inches in 9 hours; the maximum depth of water over the waste weir was 2 feet, and the overflow continued for 29 days. The total monsoon rainfall of the year was 26·74 inches. In 1889, with a rainfall of 25·77 inches, the reservoir again filled. In 1890 the reservoir filled to the 34-foot contour, or 6 feet below waste-weir level, while in 1891, the year of famine in West Rajputana, only 6·04 inches of rain fell on the catchment area, and the reservoir again remained unfilled; but in 1892 38·36 inches of rain fell in the monsoon, and the reservoir filled to overflowing. In 1896, a year of almost universal famine in India, the reservoir filled to within 6 feet of the waste-weir level, and the water was the salvation of the surrounding districts. It would thus appear that to provide for an average rainfall the capacity of the tank has been very correctly estimated. The result of 14 years' observations gives 21·82 inches

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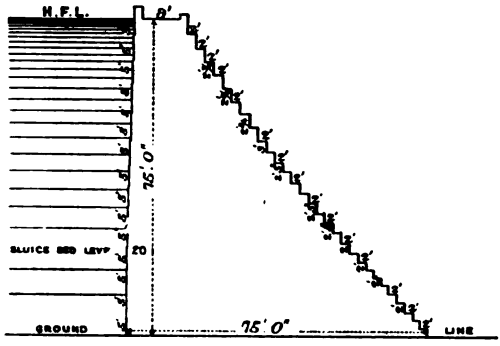
as the average annual rainfall of the district, and the capacity of the reservoir being 1,758 million cubic feet, it would appear that on the average only 2·25 inches of the whole rainfall runs off, that is, about 10 per cent. The high-water level was fixed at 40 feet, and could not be raised without submerging the village of Miron, which was not advisable. It is an interesting fact that since this work was finished no less than 35 new hamlets have been established in the land irrigated by the lake, where formerly nothing but jungle existed.

### Boochara Reservoir.

In the hills near Boochara, about 55 miles north of Jeypore, the waters of the Sota River have been impounded by a masonry dam

*Fig. 2.*




Scale, 1 inch = 40 feet.

Cross-Section of the Boochara Dam.

80 feet in height at a point where it emerges from a hilly tract about 80 square miles in area. The length of the dam is 480 feet at the top and 130 feet at the bottom, and was purposely made somewhat thicker at the base than was theoretically necessary (*Fig. 2*). The area of the reservoir is 1·75 square mile at top-water level, the greatest depth being 75 feet, and the total capacity 1,328 million cubic feet. Two low places in the circumference have been closed by earthen banks, and two or three other places by masonry dams. The outlet sluices are situated at a different point, a channel being cut through the rock from the reservoir to them. They are in duplicate, one set in the outer, the other in the inner wall. In front of the sluices a masonry wall with two grooves has been provided, in which planks can



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be inserted in order to examine or repair the sluice valves. There are three waste weirs, two to the south and one to the north of the main dam, having an aggregate length of 746 feet. The length of the main and irrigation canals is 73·75 miles.

The total expenditure up to 31st December, 1895, has been Rs.3,20,487, and the average annual revenue realised Rs.19,155, or 5·98 per cent. on the total cost of the work.

The part of the country in which the lake is situated was formerly notorious as the resort of dacoits.

The work was commenced in March 1884. A solid rock foundation at the site of the dam was obtained, 15 feet below the bed of the river, but the work on the foundations was seriously delayed in June by floods, and after the rains ceased malarious fever and dysentery attacked the workpeople. It was noted as a remarkable fact that those who were encamped on that side of the river which was exposed to the prevailing south-west winds sweeping over the basin of the proposed lake, suffered very badly from fever, while the windward side of the river remained comparatively healthy. The same phenomenon has been observed at Jeypore in the case of the Amanisha River at the waterworks reservoir, the healthy side being the windward side of the river.

In the following year, 1885, the fever was again so prevalent that nearly 6 working months of the year were lost.

About 1,600 men were employed on the work, and over 400 bullocks, donkeys, camels, &c., for transport of material. During this year the dam was carried up to a height of 40 feet, and all surplus water coming into the reservoir during the rains flowed over the uncompleted dam. The work was directly in charge of a native assistant-engineer and two sub-overseers.

Some difficulty was experienced in getting the main canal away from the hills surrounding the reservoir. After passing through heavy rock cutting the canal crossed two large rivers; one of these was impounded by an earthen bank, the other was crossed by a masonry aqueduct.

On the 15th October, 1886, the dam was completed. The rainfall was short this year, and only 55 feet of water came into the reservoir. In 1887 the reservoir filled, and water, to a depth of 9 inches, flowed over the waste weir for 5 days. This was equivalent to a run-off of 23 per cent. of the rainfall. In 1888 only 16·85 inches of rain fell, and 5 feet of water came into the reservoir, raising its level to the 58-foot contour. This was equivalent to a run-off of 4 per cent. only of the rainfall. In 1889 the water rose 21 feet in the reservoir over and above the previous

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year's balance; this is 18 per cent. of the rainfall. 1890 and 1891 were bad years of rain, only 13·14 and 9·3 inches falling. 1892 was a good year, 24·65 inches of rain fell, of which 23 per cent. ran off.

SUMMARY OF RESULTS.

| Name of Work. | Drainage Area in Square Miles. | Nature of Catchment. | Average Rainfall over Catchment. | Capacity of Reservoir. | Percentage of Rainfall provided for in Reservoir. | Amount of Water stored per Rs.10 = £1, calculated on the Cost of the Dam, Waste Weir and Sluices only. | Amount of Water stored per Rs.10 = £1, calculated on the Cost of the Dam, Waste Weir and Sluices, including all Costs, Canals, etc. |
|---|---|---|---|---|---|---|---|
| | Sq. Miles. | | Ins. | Million Cub. Ft. | | Cubic Feet. | Cubic Feet. |
| Moran Sagar[1] . | 35 | Surrounded by hills . . . | 28 | 456·50 | 20·00 | 60,800 | 33,010 |
| Kalegh Sagar[2] . | 227 | Sandy and flat . | 25 | 578·75 | 4·36 | 48,050 | 24,930 |
| Tori Sagar[3] . . | 320 | Black cotton soil—flat . . . | 22 | 1,753 | 10·68 | 55,120 | 34,040 |
| Boochara reservoir[3] | 80 | Hard ground and hilly . . . | 21 | 1,329 | 34·00 | 94,810 | 49,880 |
| Amanisha water-works at Jeypore | 13 | Very deep sandy soil, except at sources . . . | 26 | 148 at 46 feet contour | [4] | 13,890 | |

In 1893 an extraordinary flood occurred on 11th July, when, although no rain fell at the site of the dam, in 8 hours the water rose from the 58-foot contour, filled the reservoir, and rushed over the waste weirs to a depth of 4 feet. As a careful record was kept of the duration of this flood, it is calculated that the actual discharge was about 15,854 cubic feet per second, as against 22,068 cubic feet per second, calculated by Colonel Dicken's formula for a drainage area of 80 square miles, and a total run-off for that day of 1,813 million cubic feet of water, or more than sufficient to fill

[1] Probably 25 per cent. might have been provided, as this tank frequently overflows.

[2] This percentage is about correct for average rainfalls.

[3] Double the usual rainfall provided for to guard against the frequent water famines; 23 per cent. has been observed as the actual run-off from an average year's rainfall.

[4] Reservoir has never filled beyond the 31½-foot contour; 2 to 3 per cent. is the run-off.

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the reservoir. 1894, 1895, and 1896 were not years of good rainfall. It is thus apparent that for years of normal rainfall of 25 inches, a run-off of about 20 per cent. may be expected from this hilly track, while in bad years it is as little as 4 per cent.

As the rainy season advances or is prolonged, so the ratio of run-off to rainfall increases, and no fixed percentage can be stated.

## General.

From these results it appears that with a rainfall of 20 to 25 inches per annum a run-off of 25 per cent. should be provided for in case of rocky ground in hilly districts, 10 per cent. in flat black cotton soil country, and 5 per cent. where the catchment is sandy. The larger the rainfall of course the greater the proportion of run-off, as shown by the results of Mr. Binnie's observations at Nagpore.

The total number of completed irrigation works in the Jeypore

| Year. | Amount Expended. | Revenue. |
|---|---|---|
| 1868 . . . . | 227 | |
| 1869 . . . . | 23,853 | |
| 1870–71 . . . | 22,772 | |
| 1871–72 . . . | 44,529 | |
| 1872–73 . . . | 68,019 | 4,337 |
| 1873–74 . . . | 63,590 | 5,623 |
| 1874–75 . . . | 52,690 | 15,919 |
| 1875–76 . . . | 70,452 | 6,443 |
| 1876–77 . . . | 2,26,038 | 10,649 |
| 1877–78 . . . | 1,52,663 | 22,590 |
| 1878–79 . . . | 1,25,218 | 21,900 |
| 1879–80 . . . | 1,20,766 | 66,589 |
| 1880–81 . . . | 1,28,588 | 79,962 |
| 1881–82 . . . | 1,42,765 | 65,205 |
| 1882–83 . . . | 2,38,624 | 1,39,281 |
| 1883, 9 months . | 1,67,207 | 1,62,065 |
| 1884 . . . . | 3,11,440 | 1,25,730 |
| 1885 . . . . | 4,28,511 | 1,35,117 |
| 1886 . . . . | 2,80,592 | 2,01,600 |
| 1887 . . . . | 2,97,408 | 1,65,778 |
| 1888 . . . . | 1,93,357 | 3,09,775 |
| 1889 . . . . | 1,22,420 | 2,74,600 |
| 1890 . . . . | 1,13,767 | 3,19,072 |
| 1891 . . . . | 96,855 | 2,43,831 |
| 1892 . . . . | 2,18,851 | 1,91,771 |
| 1893 . . . . | 2,55,879 | 2,67,491 |
| 1894 . . . . | 2,56,778 | 2,47,845 |
| 1895 . . . . | 1,53,435 | 2,55,526 |
| 1896 . . . . | 1,40,465 | 3,23,286 |
| Total Rupees . | 45,17,759 | 36,61,985 |

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State is 138, with a storage capacity of 11,141·65 million cubic feet, irrigating 124,002 Jeypore Bighas, which is equivalent to about 41,334 acres.

This does not include the water stored in Zemindars' tanks, which is not available for irrigation, but is used for drinking and ablution purposes only.

It has been found that an allowance of 40,000 cubic feet of water per Jeypore Bigha, or 120,000 cubic feet per acre, is sufficient to provide for all contingencies, including loss by evaporation and absorption. In black cotton soil one watering is often sufficient, while in the lighter soils two are required.

In studying the column of figures in the above Table, it should be remembered that it is frequently cheaper to build the dam a little higher than to cut down the ground to form a waste weir, especially if the site of that weir is in hard rock, as is generally the case, so as to withstand the rush of water over it when the reservoir fills. Increasing the capacity of the reservoir, moreover, has the additional advantage of storing the heavy rainfalls and the surplus of years of heavy rainfall, and thus helps to tide over the dry years, while the additional area of the lake at high-water level reduces the necessary length of waste weir.

On the preceding page is a Table showing the expenditure on these works since 1868, and the revenue realized.

The Paper is accompanied by nine tracings, from a selection of which the Figures in the text have been prepared.

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(*Paper No. 3156.*)

# "The Victoria Bridge over the Dee at Queensferry."

By THOMAS WALTER BARBER, M. Inst. C.E.

THE Victoria bridge, recently erected for the County Council of Flintshire, replaces an old ferry across the Dee on the main high road between Liverpool and North Wales. Originally the Dee estuary at this point was about 1 mile in width, but a large portion has been subsequently reclaimed by the Dee Company, and the river is confined to an artificial cut about 400 feet in width. The design adopted was suggested by the very stringent conditions laid down by the County Council, who offered a premium of £100 for the best design for an opening bridge, stipulating, among other conditions, that (*a*) the piers should offer the least possible obstruction to the current of the river, and (*b*) that its cost should not exceed £13,000. These conditions practically precluded a swing-bridge, and were almost impossible of fulfilment by any other of the customary types. The Author therefore prepared a design for a telescopic or rolling girder bridge, which was accepted and in due course erected.

The problem of designing a simple and satisfactory opening bridge at a moderate cost has always presented considerable difficulty to engineers. Swing-bridges require massive piers for the swing span, such piers being costly, especially in a sandy foundation liable to heavy scour, which is intensified by the obstruction such piers present to the current. Bascule bridges also require substantial piers; and both types are expensive in the necessary motor machinery, pivoting centres and guiding races. Both descriptions of bridges become occasionally unworkable in high winds, and the swing-bridge usually requires large and expensive fenders to protect the span from drifting vessels while opening or standing open. The telescopic system designed by the Author seems to avoid all these difficulties successfully. The piers and fenders required are the same as would be necessary with a fixed bridge under the particular circumstances. The moving spans offer very little resistance to wind-pressure, and such resistance

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does not vary, as in the other types, during the movement, but is practically constant. The motor machinery and travelling gear are not so costly as in either of the other types, and the Author is of opinion that an opening bridge on the telescopic system can be constructed at between 50 per cent. and 70 per cent. of the cost of any other type.

The Victoria bridge at Queensferry consists of three spans, as shown in Figs. 1, Plate 7, the central one being movable and having a clear opening of 120 feet; the two side spans are each 140 feet, and are fixed. The central span is in halves, meeting at the middle of the opening; each half therefore projects 60 feet from the fixed span and constitutes a cantilever of that length. This is extended 40 feet within the fixed span and is balanced by dead weight at its inner extremity. Thus the moving half-spans are each 100 feet in total length, the girders being 13 feet centre to centre, and are moved in and out on twelve travelling wheels, 4 feet 4 inches diameter, placed on either side of each of its two main girders, which run on four longitudinal rolled girder paths, 18 inches by 6 inches. The construction and working are shown in the longitudinal section of one half of the bridge, Fig. 2, Plate 7. As the 60-foot cantilever portion of one half-span is balanced by weights at the extremity of the 40-foot inner extension, the load may be considered as resting at the junction Y of the 60-foot cantilever with the 40-foot carriage, and is carried at this point by eight of the twelve wheels, the other four at the balance end Z being merely guide wheels.

The weight of the movable half-span is 90 tons. The fixed spans are formed of two main girders, 20 feet centre to centre and 13 feet deep, of the Linville type, with box flanges, vertical struts and diagonal ties. These have box end pillars built into the abutments at one end and resting on cap girders over each pier. Cross girders 18 inches by 9 inches connect the lower flanges of the main girders and carry the four 18-inch by 6-inch longitudinal roller paths on which the moving half-spans travel. The top flanges are substantially stiffened by the trough decking which is riveted to them. This is of the usual section and 12 inches deep, pressed cold by hydraulic dies from ¼-inch steel plates in one length of 28 feet; it is fixed transversely and filled with lime concrete, on which is laid asphalt and 5-inch wood brick paving. The ends of the troughs are covered with a cast-iron moulded facia which is surmounted by the hand-railing.

As the moving half-spans require to be braced vertically and horizontally to form stiff independent structures or carriages

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this is effected by framed cross bracings, but there are no cross girders to carry the roadway platform.

This platform rises and falls through a vertical distance of 23 inches to allow it to pass under the fixed platform, and is also formed of trough decking similar to that of the fixed spans, but 9 inches deep and $\frac{3}{16}$ inch thick, covered with thick planking without concrete, the length of the troughs being 16 feet. The centre span of the bridge thus provides a single roadway of 9 feet and two footways of 3 feet 6 inches, the fixed spans having a double roadway of 9 feet and two footways.

The movable platform of one half-span is supported by twenty-two cast-iron swinging arms or levers, which stand vertically when the bridge is closed; these arms (shown by centre-lines in Fig. 2, and in detail, Figs. 3) are keyed in pairs to eleven transverse steel shafts, $4\frac{1}{2}$ inches diameter, carried in bearings fixed to the main girders; the upper ends of the arms are forked and connected by pins to bearings on the underside of two 12-inch by 5-inch longitudinal rolled girders, to which the platform troughing is riveted. As the arms swing from a vertical position when the bridge is closed through an angle of 60° when the bridge is open, the platform must be balanced with a variable counterweight. This is effected by four balancing levers of wrought iron, Figs. 4, which are also keyed on two transverse shafts at the extreme inner end of each half-span, where the weight is most effective, and are connected at their upper ends to the twenty-two swinging supports, by two long horizontal connecting-rods. The balance weights are placed in a box suspended from the lower ends of the four balance levers, which swing through the same arc as the arms, supporting the platform and thus exactly balance it in all positions.

The rise and fall of the movable platforms are governed by segmental cam guides fixed in pairs at the outer ends of the fixed main girders, shown in Fig. 5. Cast-iron rollers run in these guides strongly secured to each movable platform, which give it its upward and downward movement at the exact point required. The rise and fall of the movable platforms are therefore effected by means of the horizontal travel of the moving spans without any separate motive mechanism.

As the movable platforms have to pass under the fixed platforms, it is evident that the hand-railing must do likewise. This is effected, as shown in Figs. 6, by jointing it into a sort of parallel motion by its vertical standards which are pivoted at the bottom to brackets on the main girders, and at the top to the hori-

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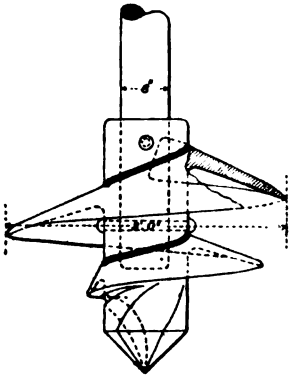
zontal bars of the hand-railing, and intermediately to pins fixed to the edge of the movable platform, so that as the latter rises and falls the railing opens up into position or collapses down into a small space level with the platform.

The motive power is hydraulic, and consists of an accumulator, 15 inches diameter by 12 feet stroke, loaded with 60 tons of cast-iron rectangular weights suspended from a massive crosshead by four 2-inch steel bolts. The working pressure is 700 lbs. per square inch, and is conveyed by 2-inch diameter steel pipes to two 8-inch diameter and 11 feet 6 inches stroke hydraulic multiplying cylinders, laid horizontally on the cross girders of each fixed span and geared 6 to 1; one ram opening the bridge and the other closing it by means of 1-inch diameter steel-wire ropes, which are attached to a cross girder on the lower flanges of the movable main girders. The opening or closing movement is effected in 1 minute and could be done in ½ minute if required. Check valves, having a gradual movement, govern the inlet and outlet ports of the hydraulic cylinders to stop the moving spans without shock.

*Fig. 7.*



Scale, ¼ inch = 1 foot.

The motive power consists of a pair of vertical duplex pumps, and the boilers are of the vertical cross-tube type of 8 HP. Pumps and boilers are in duplicate, and each pump is capable of filling the accumulator in 7 minutes, its contents being sufficient for nearly two single movements of the bridge. The engine-house contains also stores, a keeper's room, and a watch-tower, in which is placed the lever controlling the working of the bridge. Signal lamps, automatically arranged to show red or white lights, are provided, and automatic road bars to stop traffic when the bridge is open, both these being operated by the bridge itself as it opens or closes.

The two piers are formed of clusters of screw piles, each cluster consisting of ten 6-inch diameter solid steel piles fitted with the Author's patent mushroom screws, 3 feet diameter, and screwed to depths of about 18 feet into the river-bed, which is a fine sand extending to a depth of probably 100 feet. These screws, *Fig. 7*, have dished flanges and an increasing pitch upwards. The dishing of the flange considerably strengthens the screw and

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increases its bearing power, while the graduated pitch enables it to enter with less slip than usual, and to clear itself better than the ordinary flat flange screw of regular pitch. Each pile was tested with 30 tons dead load for 3 days and the greatest settlement observed was $\frac{3}{8}$ inch. The piers are braced horizontally and vertically by channel-bars and tie-rods, and are surmounted with cast-iron caps and steel-plate cap girders riveted into one piece covering the entire pier. Each pier is protected by two groups of fender piles connected together by long horizontal walings, but not attached to the pier itself, so that blows from passing vessels are not communicated to the bridge structure.

A difficulty arose in connecting the hydraulic cylinders on the Cheshire side of the river with the accumulator-house which is *on* the Flint abutment, necessitating the laying of pressure pipes across the bed of the river. The bed of the river was found *to* shift continuously, and was at times subject to extensive scour, so that some flexible form of piping, which would sink into the sand at every point where scour occurred and ultimately settle below the scouring action, became necessary. Annealed copper pipes, $1\frac{1}{2}$ inch diameter and $\frac{5}{16}$ inch thick, have fulfilled this purpose admirably, and the difficulty of a satisfactory joint has been overcome by a form of sealed screwed union in which the union is extended in a plain sleeve $1\frac{1}{2}$ inch beyond the screwed joint, and the space between the union and the pipe heated, tinned, and filled with hard solder and the joint caulked. This joint is cheap and effective and will bear much bending or vibration. No leak has occurred in 2 years' working, but, as in the case of the engines and boilers, these pipes were also laid in duplicate to prevent any chance of rendering the bridge unworkable from their failure, which might occur from a vessel's anchor dragging. Each half-span is, however, also provided with a hand-winch gear for use in emergency.

Another difficulty that arose was the prevention of freezing in pipes and cylinders during winter. It is evident that in such an exposed position no method of clothing or heating the pipes would be reliable, besides being necessarily incomplete. It was decided therefore to circulate the water in the pipes and cylinders by a small steam-pump during frost, and special valves were fitted for this purpose; the water circulates from a tank in the engine-house, into which the exhaust steam is turned to warm the water. This plan has been thoroughly effective, and has the advantage of being easily controlled by the engineer in charge by very simple means.

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The bridge was opened by the late Mr. W. E. Gladstone on the 2nd June, 1897, and has been now at work for nearly 2 years without any hitch or stoppage. Its principle of construction may therefore be said to have established for itself a reputation for reliability as well as novelty.

The Paper is accompanied by five tracings, from which Plate 7 and the Figs. in the text have been prepared.

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(*Paper No. 3166.*)

# "Breaks in Submarine Cables close to Repairs."

By ANDREW GRAY, Assoc. M. Inst. C.E.

THAT breaks in submarine cables occur, apparently in consequence of repairs under certain conditions, is well known, but their primary cause is not generally appreciated. The Author has observed the circumstances connected with such breaks, and proposes to give an account of their origin, which appears to explain their relationship to previous repairs. These breaks usually occur in old cable at a distance of more than the depth of water[1] from the repair by which they are apparently caused, and the ends at the break are corroded to sharp points ("needle points"). The corrosion is quite local—over a length of 1 fathom or 2 fathoms—and any wires that may show fracture invariably indicate clean tension. As a break cannot take place without force, it may be shortly stated, that these breaks are caused by corrosion induced by the operations of the repair and tension as a direct legacy from it.

To discover how these conditions may arise, suppose the case of a cable of considerable age requiring to be repaired in a depth of 1,000 fathoms. Assume the cable to weigh 1 ton per mile in water, and to have been laid with 8 per cent. of slack, and suppose a bight to have been raised to the surface. Then, the cable not being broken, under normal conditions about $3\frac{1}{3}$ miles of cable would be suspended,[2] and a total length of about $11\frac{1}{2}$ miles would have been disturbed, 4 miles on the bottom on each side of the suspended cable having been dragged over the ground to supply the slack for lifting. The total weight of the bight would be about $3\frac{1}{2}$ tons, and—the angle at the surface being about 60°—

[1] This fact in many instances obscures the connection between the break and the previous repair, but it is an important point in the explanation suggested here.

[2] *Electrician*, 18th February 1898.

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the maximum tension in the cable would be about 2 tons, and the horizontal tension at the point where the cable touches the ground 1 ton, falling to zero in the undisturbed cable outside each of the 4 miles of dragged cable. The whole of the 4 miles of dragged cable would evidently be in tension resisting the horizontal tension of 1 ton, showing a coefficient of friction of 0·25 between the cable and the bottom.[1] Now, assume that one side is buoyed off, and that after whatever operations the repair may have necessitated on the other side, new cable is paid out up to the buoyed end, and that the "final splice" is made and slipped. Then, the condition of the old cable on the final splice side of the repair will be as follows:—First, a length exceeding the depth of water, in the immediate vicinity of the new cable, will lie easily on the bottom with plenty of slack from the suspended bight at the splice, and will be therefore fairly secure against rupture in the future. Second, outside this there will be the length of 4 miles of dragged cable without slack; in which experience teaches that the corrosion and tension that produce breakage may be sought. As it is impossible to observe the actions at work on laid cable, it is difficult to state what may be the cause of the corrosion. Judging, however, from the evidence that can be gleaned from recovered cable that has been years on the ground, abraded and chafed places in the external semi-insulating serving, if they are not causes of corrosion, at least lead to it.[2]

In respect to tension, remembering that cable has elasticity, and when strained becomes a potential source of energy, it is seen that once a length of cable on the ground has been strained, this elastic energy, combined with the friction between the cable and the bottom, will maintain in it a tension of at least half the maximum stress to which it has been subjected, after the cause of that stress has ceased to exist.

Here then, in the 4 miles of dragged cable as a result of a repair, are conditions conducive to rupture. For the extreme drag in that length amounting to 0·32 mile, and the drag at the probable point of maximum tension amounting to 0·16 mile, would, presumably, be sufficient to damage the external serving of cable not in its first youth, and so lead to corrosion, while the

[1] This of course is an assumed case. There appears to be no fixed rule for friction between cable and bottom. In some cases it is very great.

[2] Electrolytic action, whether due to variation in the nature of the bottom or concentration of earth currents at the abraded places, seems to be largely responsible for the actual corrosion.

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elastic energy of the strain would supply the necessary stress to effect the actual parting.

This conjunction of conditions conducive to rupture, at a position in such peculiar agreement with what observation shows to be usual, if not proving that these conditions are the sole causes of the rupture, certainly supplies sufficient reason for considering them as very largely instrumental in producing it, and the explanation given may therefore safely be adopted as a working hypothesis.

From this it may be deduced that in general, irrespective of the varying circumstances of different cases, excessive dragging of old cable is the principal cause of breaks attributable to repairs, for dragging includes tension and corrosion as cause and effect.

No account is here taken of extraneous influences which exaggerate the trouble, still it should be pointed out that the evil effects of a hard and uneven bottom are more marked on that portion of the cable which has been shown most liable to rupture; for evidently ridges will cause most abrasion where there is most drag, and depressions most energy of suspension where there is normally most energy of elasticity.

To minimise future trouble as a result of repairs the old cable which is to remain in the section should be subjected to as little dragging as possible, or when dragging is unavoidable, the dragged cable should be removed. Also, in laying a new section, the cable used should have a minimum of elasticity and a maximum of protection from corrosion, and particularly the sheathing wires should be separately served to obviate the denuding of the whole at once by local abrasion.

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(*Paper No. 3188.*)

# "The Evolution of the Stationary Steam-Engine."

By ANDREW ROBERT ROBERTSON.

IN the time of Newcomen the steam-engine was used only as a means of driving a pump, as the natural outcome of the older idea of elevating water by displacing it with steam. Savery's engine, or pump, worked on the latter principle, but the limits of the conditions under which it would act were so quickly reached, that Newcomen's engine soon after its advent almost entirely replaced it; but although at that time unable to do the work demanded of it, modern methods and knowledge have enabled Savery's engine to reappear in the many forms of Pulsometer pumps.

Early engines were called "fire-engines," and are now classed as "atmospheric," the steam having been used not as a direct means of driving, but only to displace the air in the cylinder, which, in condensing, produced a vacuum on one side of the piston and allowed the pressure of the atmosphere to act on the other side.

Since the days of Newcomen the name most intimately connected with the steam-engine is that of James Watt, and in his hands it assumed a shape and embodied principles which later engineers have not altered but only added to and improved. To show, therefore, that the main features and principle of the engine as laid down by Watt and his contemporaries differ only in detail from those employed by successive experimenters and designers will be the main object of this Paper.

Watt began his study of the principles of Newcomen's engine by investigating the quantity of water necessary to condense a given amount of steam, with the object of determining the temperature corresponding to various steam pressures. These experiments soon showed him that the Newcomen engine required more water to effect condensation than the volume of steam in the cylinder warranted. This apparent anomaly gave Watt his clue. Why should the engine in practice demand more condensing water than was necessary to condense the same volume of steam experi-



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mentally? The only answer that reasoning gave was, that in some way more steam than the content of the cylinder was being used at every stroke. Further consideration pointed to the fact that when the steam was admitted into the cylinder a considerable amount was condensed by the walls cooled by the condensation of the previous stroke. The separate condenser was thus suggested as a means of preventing this excessive cooling and reheating of the cylinder, and Watt was led to announce his leading principle, viz., that at all costs the temperature of the cylinder must be kept as high as that of the entering steam.

The success attending the first experiments gave Watt such encouragement that he seriously took up the improvement of the engine, and this led to the following alterations and improvements that made him famous. The separate condenser; the use of air-pumps; the steam-jacket; the expansive use of steam; governing the speed of the engine; guiding the piston-rod; improvement of cylinder details; the manner of converting reciprocating into rotary motion; the admission of steam to both sides of piston; the steam-engine indicator; the engine-counter and the pressure-gauge.

The separate condenser led to the use of the air-pump, as otherwise the vacuum formed by the condensation of the steam gradually began to fail owing to the accumulation within the condenser of the gases brought in with the steam, and although Watt knew how to make a Torricellian condenser the height necessary was not available, and the air-pump was the natural alternative.

The steam-jacket was part of the first principle mentioned; the expansive use of steam, however, was the outcome of a separate set of observations though brought about by noticing the power given up by steam expanding into the separate condenser.

The governing of the speed came as a necessary adjunct of the automatic working of the engine which now did not require that every stroke should be watched.

The parallel motion replaced Newcomen's chain and sector, and must be regarded as a very beautiful means of overcoming the difficulties caused at that time by imperfect workmanship which rendered the slipper guides now used almost impossible. The cylinder details were improved in workmanship and design, stuffing-glands and properly made pistons were used, and ultimately correctly bored cylinders became a possibility.

The converting of the reciprocatory movement of the pump into a rotary one required for driving a fly-wheel was most simply performed by the crank and connecting-rod; but this ancient

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device was patentable at the time, and Watt was forestalled, hence his invention of the sun-and-planet gear.

The admission of steam to both sides of the piston completed the making of the steam-engine type, and the recording instruments, the indicator, the pressure-gauge, and the revolution-counter, enabled Watt to determine if his designs developed the results anticipated.

Watt's work was essentially practical in the true sense of the word, in that he combined a thorough study of what theory he could master with his experimenting—in fact, his philosophy was absolutely experimental. In all work, however, the results obtained are apt to make the originator pay more attention to engineering details rather than to pure philosophy, and as a result the precise study of abstract principle is generally left to theorists who make a life-work of such subjects. In Watt's case there was a commercial end in view; and while, therefore, the engine owes most of its details to Watt, it owes much of its modern efficacy to those who, making thermo-dynamics their special study, put Watt's discoveries into scientific form, laying down certain rules and principles which all heat-engines should follow.

Watt himself enjoyed the friendship and help of Dr. Black, of Glasgow; but it is to Sadi Carnot that the honour must be given of originating the study now called Thermo-dynamics, which has been inseparable ever since from the proper understanding of the steam-engine, all problems of the modern heat-engine of whatever form being discussed with due consideration of both Thermo-dynamic theory and practice; the abstract theory being limited by the possibilities obtainable in practice, and if the word is properly used including these limitations as part of the theory. Since Carnot's time the theory has been more clearly elucidated, and the limitations of practice not only more clearly defined, but diminished, and the two brought into better relation, and therefore the theory is now placed in due and proper relation to the expediency of manufacture and the use to which the engine is to be put.

Having stated the principle of the separate condenser and worked in accordance with it, Watt obtained a result considered satisfactory; but his successors, aided by the theorist, have become more familiar with the principles and apply them further.

The effect of the cold cylinder is now called initial condensation, and after Watt's time it came to be recognized that in removing the condenser from the cylinder all the causes of initial condensation did not disappear, and means of decreasing them were sought.



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The steam enters the cylinder at a pressure above that at which it leaves it, and therefore the incoming steam meets a cylinder cooled by the exhaust. Consequently modern engineers, in trying to make the difference of temperatures of entrance and exit as small as possible, compound the engine. This action may fairly be described as a further carrying out of the principle of Watt's separate condenser, and it may be accurately said that engineers have simply moved the condenser further from the engine. Compounding is also intimately connected with the use of high-pressure steam, as the long ranges of expansion which would otherwise be necessary render it especially advantageous. That the efficiency of the engine is raised by the use of high-pressure steam is clear when Carnot's statement for the efficiency of a heat-engine is considered. This shows that the efficiency of a perfect heat-engine depends wholly on the difference between the temperature of entrance and exit of the working fluid, and though the steam-engine is not a perfect "heat-engine," it belongs to that class and is governed by the same thermo-dynamic laws.

The value of Carnot's statement of efficiency,

$$\frac{\text{Temperature of entrance} - \text{temperature of exit}}{\text{Temperature of entrance}}$$

increases with the temperature of entrance, so that the higher the pressure the greater the efficiency, and modern practice therefore tends towards the highest pressures consistent with safety and durability.

High-pressure engines (so called) are mentioned by Watt in his patents, but he did not employ them. It was for Trevithick, his competitor, to be the pioneer of high-pressure steam, and next to Watt he must be considered as having exercised the strongest influence on the later history of the engine. From a study of his life it would appear that he lived before his time with great ideals which, hampered by circumstances, he had perforce to leave to others to perfect. Watt, content to make his engine as perfect as circumstances would allow him, outlined possibilities he considered beyond the power of his generation. Trevithick, on the contrary, went boldly at apparently insurmountable obstacles, and produced engines that would now be considered criminally unsafe. He drove his engines with high-pressure steam generated in the crude, leaky boilers of that day, at what must then have been considered a high speed. Nevertheless, the combination of Watt's engine with Trevithick's use of high pressure completed the typical engine. Watt and Trevithick found it an "atmospheric engine,"

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made it into a single-acting steam-pressure engine, and finally left it in the form of a double-acting high-pressure steam-engine.

The steam-jacket was a natural outcome of Watt's statement that the cylinder should be kept as hot as possible; but though one of his inventions, he made less use of it than did Trevithick, who seems to have used it as few engineers do now. In his characteristic style he did not employ steam for his jacket, but passed the flue gases round his cylinder, and thus obtained a far more efficient jacket than the low-pressure steam-jackets which so many of his successors have thought of so highly. The value of the jacket is or was much discussed, but it has come to be recognised that the steam used for this purpose should be high-pressure boiler-steam and not steam below the temperature of that admitted to the cylinder, because the jacket is to impart heat to the working fluid to overcome "initial condensation" and assist "re-evaporation," and will therefore be the more efficient as a jacket the higher the temperature of the steam it contains and the more perfectly it is drained. Therefore Trevithick's use of the hot flue gases was strictly correct and the increased economy thus obtained is readily understood.

To the use of superheated steam, still periodically brought up for discussion and experiment, Trevithick also paid much attention. It also is a means of attacking the initial condensation, and the advisability of its use is now limited to that temperature that can be used without injury by burning, first the superheater and second the oil lubricating the valves and piston-rings of the engine. This question of high temperatures also applies to the use of high-pressure steam, but not to the same extent, as the very water of initial condensation assists lubrication.

The expansive use of steam and the economy to be gained thereby, were clearly understood by Watt, but were not employed by him as often as he would have liked, as there was no means of preventing users of the engine from altering and disarranging the setting of the valves. The only question now to be considered in engine design in this relation is the extent to which expansion is to be carried, as with too much, other matters are brought into consideration, viz., in compound engines the increased friction caused by the complication of moving parts, and in simple engines the extra range of temperature in the cylinder and consequent troubles caused by initial condensation; while in both, the extra surface necessitated by the larger cylinder gives more play to loss by condensation and radiation.

Although Watt originally intended in introducing steam to both

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sides of the piston to reduce initial condensation, it resulted in enabling him to obtain more work from his engine without increasing its size, and the double-acting engine became the general type, till of late years the use of very high speeds has led to a return of the single-acting form in order to obviate the shock and noise caused by the rapidly moving reciprocating parts, the designer of high-speed engines finding that the single-acting form allows of otherwise impossible piston-speeds by keeping the pressure on his pins, etc., always in one direction.

The perfection of valve-gears is intimately connected with that of the engine, and they have a history as wonderful as its own. The first valve-gear has been termed the "crude artifice of a lazy boy who desired to shirk his work." This is a decidedly opprobrious term to apply to one of the earliest labour-saving devices, and to-day, when the greatest incentive to the inventive faculty is the "saving of labour" this jibe should be forgotten, or serve rather as a sign of want of appreciation on the part of those who use it of the merit of Humphrey Potter's crude idea which only required the touch of Smeaton's hand to become a veritable valve-gear. Valve-gears, in spite of their great variety, may be divided into two distinct classes, namely, those working independent valves where each valve has only one function, and those working slide-valves which have many.

The first was the form of gear employed in the earliest engines, and, although modified to suit modern requirements, it is still used. It is, however, now divided into two great classes, namely, valves worked positively and those which at certain moments lose their direct connection with the engine and complete their cycle under the influence of some other mechanism. The use of the latter may be considered to mark an epoch in the growth of the large stationary mill engine, as they came into use when the economical production of large powers was being more carefully considered, and they were accompanied by a better application of first principles; in themselves, however, they do not necessarily suit all conditions, and the misuse and over-complication of drop or Corliss cut-off gear has often proved a stumbling block to successful design. The second great class represented by the slide-valve had also an early origin, being generally credited to Murdoch, and though it has passed through a multiplicity of shapes, it may be briefly classified thus:—

First, the plain D slide-valve actuated by a simple eccentric which in all treatises on valves serves as an exposition of the first principles of valve-gear. Second, the slide-valve actuated by a

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link and two eccentrics; this is the most ingenious arrangement ever applied to an engine, as it combines in a very simple manner more possibilities and applications than almost any other part of the engine. We do not know that Stephenson really understood all the possibilities of the link, but in the hands of modern engineers it has, in its latest form, its place in many types of engines. Third, the shifting eccentrics, which enable changes and reversals to be made such as fixed eccentrics do not allow of. Fourth, the double valves, which give variations in the cut-off and allow of governing by the amount of expansion. Fifth, the so-called radial class, which, actuated by an eccentric, have their motion modified by some arrangement of radius rods worked by some other part of the engine.

Watt and his contemporaries having established the principle of the expansive use of steam, subsequent inventors seem to have devoted most of their energies to the design of valve-gears, most of which are now unknown. The modern engine should be as simple in all its details as good working will render possible, and all the wonderful valve gears belong to a sort of "middle age" in the history of the engine. The plain slide-valves with some of its better developments, the piston-valve, the independent positive valve-gears, and the better forms of drop cut-off or Corliss gear are now the principal forms employed, but whatever is used the greatest simplicity possible is always sought.

Valve-gears naturally suggest governors, which in the development of the engine have passed through many stages of complication only at length to be cut down in modern practice to their simplest elements. Watt's cataract governor has now become the dash-pot; his centrifugal governor as a means of regulating the throttle-valve remains much as he left it, but its uses have been extended and its theory mastered in such a way as to leave it now only an outward semblance to Watt's original form. After its application to the throttle came its application to the cut-off, and the greater number of modern governors alter by means of various mechanisms the amount of expansion of the steam in the cylinder. These are the principal methods of governing, though the intermediate mechanisms differ with the valve-gear, and in many cases show a complete departure from Watt's ideas.

Apart from consideration of details, their particular application merits attention, and it is the modern engineer's knowledge of how to make his engine best fit the conditions it has to work under, which is one of the chief characteristics of modern engineer-

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ing, and in this connection the much abused word "economy" must be considered, and its meaning coupled to that of "expediency," before any engine is passed over as uneconomical or unsuited to its work. For example, the large powered multiple expansion condensing-engine, fitted with all possibilities in the way of steam-saving appliances, carefully housed and looked after, never allowed to get out of order, receiving its steam dry and at unvarying pressure from a battery of economical boilers, fed by mechanical stokers, etc., and whose load is nearly constant, is a very different machine from the engine which goes out to the Colonies, getting little or no attention, whose load is far from constant, receiving steam of all pressures and all degrees of dryness, which is started and stopped at irregular intervals, and must lie idle for months, instead of starting regularly every day; yet both may be best examples of their respective types. The engineer has always to consider the local circumstances, and make his engine so that it is in the true sense the most economical. Thus in the spinning mill he has an engine of regular habits, which during its long life has a daily consumption of expensive fuel, a small saving of which soon repays the engine's first cost, but in the engine which uses cheap fuel he has an example of a possible saving so small as not to repay its cost. Again, the engine carefully looked after may have a design which would be impracticable in the case of the one constantly abused, and in many instances hundreds, or it may be thousands of miles away from the possibility of obtaining spare parts. The multiple expansion and condensing engine also have their special application, and in the sugar factory or refinery, or in the dye-house, where steam is used for evaporating purposes, not only is the condenser not used in connection with the engine, but the engine actually exhausts against a considerable back pressure, the exhaust steam passing to the evaporating vessels and thus being utilised as regards the factory in a much more economical manner than would have been otherwise possible. These latter examples must be as engines uneconomical, because of the abuse they receive. They must possess great simplicity of design, and the fewer refinements the better. They often work only one hundred days in the year, and then must of necessity come to pieces, to avoid destruction from corrosion. The repairs they receive depend on circumstances and are often very crude. The questions of weight and space bring in other considerations, and the high-speed engine, with its short stroke and large number of revolutions, belongs to another type, which, while embodying all the principles used on other types,

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calls for qualities and differences in detail which are elsewhere out of place. There are also engines which are started and stopped at short intervals, say every 15 minutes or so, whose duty is to do a large amount of work suddenly, and which are stopped almost as soon as they reach full speed. Such engines are those used to drive hydro-extractors, or rolling mills, and would be out of place where long continuous work is desired. Another example is offered by the comparison of fire-extinguishing pumps and the waterworks pumping-engine. The one has to throw a maximum amount of water for a short time, utterly regardless of expense as to fuel and steam-consumption, but the other has to work continuously, and its fuel bill has to be paid by the ever inquisitive ratepayer, and must therefore be calculated in proportion to the water pumped. The foregoing examples will be sufficient to show how any improvement on the engine of the earlier days must be considered as an improvement only when properly applied, and an engine which is perfect in one place is by no means so in another.

The principles concerned in making the engine were mostly outlined by Watt, but their better understanding belongs to the later engineers. The thermo-dynamics of the engine come first, and it is entirely due to the modern perfection of this study, both abstractly and experimentally, that the modern designer is able to take full advantage of the power stored in steam without losing efficiency in one direction while seeking it in another. For instance, expansion can be carried to a degree which renders its use uneconomical, as also compounding and the proper extent to which these can be with advantage pushed depends on a perfect understanding of the properties of steam not only as steam, but also as steam in its relation to the engine. This again introduces the commercial consideration, and it is often hard for the abstract theorist to understand that the price of fuel, the nature of the work expected, etc., must all find a symbol in his formulas. This principle must, for want of a better expression, be called "Theory in relation to expediency." The purist will consider that true theory takes due account of expediency. But in the ordinary acceptance of the word "theory" it does not, and, as a result, engineering papers are full of so-called conflicts between theory and practice.

The one principle which is entirely modern and which has made the noiseless high-speed engine a possibility is that of dynamic balance. It is true that early engines were to a certain extent balanced, but these early attempts only exemplify static balance, which being used on engines of low speed was quite

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sufficient. It was not until the introduction of higher speeds showed a necessity for better balance of moving parts that a study of the principles involved was necessitated. This subject has been of late given a great amount of attention and is yet subject to continual research and discussion.

All effects are due to causes known or unknown, and any treatment of the development of the engine would be incomplete without reference to those at work in the evolution of the engine as used to-day. First the pressing need of some means of applying greater power to a pump than that exercised by human or animal labour brought Savery's engine into being, which in its turn was replaced by the more powerful Newcomen engine; the latter was, however, such a "steam-eater" as to almost nullify the profit to be gained by the greater depth at which it allowed the Cornish mines to be worked. Watt was, therefore, met by a great demand for an economical pumping-engine, which he supplied; had the engine, however, merely remained as a motor for pumping plants, it would probably not have developed to the extent it has. But if a demand at times calls forth a supply, a supply may in its turn create a demand. The engine being in existence, there was no reason why it should not be used to drive other than pumping machinery, and this extended use caused its ultimate development. At first the process was slow, and the pump was regarded as such an integral part of the engine that water was actually pumped on to a water-wheel in order to do work. Gradually, however, the engine was separated from the pump and put to do work alone, from which point its evolution may be said to begin. First the increased power given by the still imperfectly made engine allowed of improvements in manufacture; improved methods of manufacture led to improvements in the engine itself; finer and heavier machinery to make it evolved the more skilful workman, the designer, and the theorist; and so each advance on one side or the other leading to advances on all the others, till, increasing commercial demands aiding, the many types of heavy-powered engines of modern days grew by a process of evolution from the seeds sown by Newcomen, Watt, and Trevithick.

The development of the engine, while extending over considerable time and attended by such surprising results, may be briefly stated as follows: An amplification, better understanding, and extended use of the principles laid down by Watt and Trevithick. The dynamic balancing of the engine, the perfection of old details, and the introduction of a few new ones, all modified

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by proper knowledge of first principles. The comprehension of the fact that an engine must be designed for its own specific work, and, above all, that the first principle in engineering work is that good design consists in the greatest simplicity possible compatible with the object in view. When to this is added the increased perfection attainable in materials, workmanship, and instruments of precision, all is said except that stress should once more be laid on that which has really developed the engine and made it what it is, namely, the ever-varying and increasing demand for its use.

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## ENGINEERING CONFERENCE.

JUNE, 1899.

THE Conference was opened at the Institution on the 7th June by Sir William H. Preece, K.C.B., the President, who delivered the following brief Address to a combined meeting of the Sections:—

We have gathered together from all parts of the kingdom to hold our Second Metropolitan Engineering Conference; and we welcome here many who, temporarily at home, pursue their ordinary work in distant parts of the Empire, or in foreign countries. We represent every department of engineering practice; and we are here assembled to discuss questions of great pith and moment, affecting the applications of the fundamental principle of energy to further the interests and promote the comfort, health, and happiness of mankind. Engineering does not run in one groove, nor are its votaries chauvinistic. We endeavour to benefit every race, and we welcome in our midst every nationality. We embrace in our sphere of operations the whole world. We desire to make our home in Great George Street the Mecca of Engineering; and in furtherance of this idea, I am bold enough to suggest that, at the next Conference, the Council should take measures to secure the presence of some of our members, delegated specially to represent Engineering in our Empire beyond the seas.

This Conference is not international, in the sense of that held at Chicago in 1893, or of that which I understand is contemplated for the year 1901 in Glasgow, in connection with the Exhibition to be held there; but it may well be Imperial. In whatever quarter of the globe we find ourselves, membership of this Institution has become a pass-word; and the invariable support accorded to the Institution by its members in India and the Colonies suggests the desirability of uniting them in a definite and formal manner with our proceedings on such occasions as this.

Conferences facilitate intercommunication among our members, and, by bringing us more into personal and social relations with one another, promote harmony, allay jealousy, and secure progress. Our weekly ordinary meetings are especially convenient

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for those who live in London; and the audiences are generally restricted to those occupied in the special branch of engineering under discussion at the moment. But these Conferences, in association with our annual conversazione and by combination with well-arranged excursions and visits to works, tempt many to come to Westminster who are rarely seen here, and facilitate the interchange of ideas between all the departments of our many-sided profession. They disseminate knowledge by exciting discussion, and extracting opinions from those who have acquired them from the only true master—experience—in every quarter of the world. Our weekly meetings receive and discuss Papers selected from those submitted for approval, often of the character of probational essays; they open to the young and rising engineer a means of securing the attention and the support of the *patres conscripti* of his profession. But the discussions elicited in these Conferences are based on short Papers prepared for the purpose by those who have been selected as masters of their particular subjects, and have been invited by the Council to lay the foundation of our deliberations.

After mature consideration the Council came to the conclusion that the objects of our gathering would be best secured by meeting biennially. The reasons that led to this conclusion are financial and administrative. If ever we secure another building—an event by no means improbable, and perhaps not distant, for the whole of this side of Great George Street has been absorbed by the new design for Government offices—I venture to hope that we shall realize the dream of our Past-President, Sir John Wolfe Barry, and have a hall large enough to hold our annual dinner, and to receive the whole of our members and their friends in one evening at our conversazione—a hall that will vie in splendour with those of the Ancient Guilds of the City of London. No Guild and no Merchant Venturers' Society ever compared in numbers and universality of operations with this Institution of ours—the home of an association which embraces every clime and knits together by physical agencies the four quarters of the world into one connected whole. Each morning's *Times* is the daily journal of the world; it is by our work that we learn what took place yesterday everywhere.

Now we have to give up our own building to the conversazione, and to throw ourselves upon the courtesy of our friends and neighbours for accommodation for the meetings of our various sections. The Mechanical Engineers have spontaneously offered us their new home, and there the sections dealing with Machinery

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and Electricity will meet. The Surveyors' Institution, before even their own formal occupation of their new building, have given us the use of their meeting and council rooms, where the sections dealing with Railways, Harbours, Mines, and Metallurgy will assemble. The Middlesex County Council have allotted to us their Council Chamber and Committee Room, where those interested in Docks, Canals, Waterworks, Sewerage, Gasworks, and Shipbuilding will come together.

The programme shows a plethora of important subjects for discussion. The visits to works will, we hope, provide objects of interest and instruction to everyone. Their popularity is shown by the applications which have been received from over 1,000 members to take part in them; and on the first day nearly 500 claims had to be submitted to ballot, one-half of which, I am glad to say, came from our members in the provinces. We are deeply indebted to the liberality and hospitality of those who have so kindly undertaken to meet our wishes in this essential feature of the Conference.

It was found inconvenient and impracticable to print and circulate the proceedings of our first Conference. We already receive four bulky volumes every year; and old members like myself find it necessary periodically to increase the dimensions of our libraries, and would rather experience a diminution than an increase in the number of our publications. The proceedings of the Conference are equivalent in bulk to one-and-a-half times those of our annual ordinary meetings, and comprise three times the number of subjects ordinarily discussed in an Institution Session. These proceedings are therefore thrown open to the press; and we trust that the enterprise of those admirable technical papers, which form such a credit to our industries and such a benefit to our profession, will, by the completeness of their reports and the rapidity of their issue, render full publication on our part unnecessary.

The growth of engineering is illustrated not alone by the increasing number of affiliated institutions, societies, and members, but also by the new fields of application which the advancement of knowledge and the progress of civilization are opening up. At the present moment, in ten distinct societies more or less intimately associated with our parent Institution, there are some 22,700 paying members. *Science*, a much abused term, is the systematised collection of the facts and laws of nature, and *Engineering* is their practical application to the use and convenience of man. There is a great tendency to put the cart before the horse. Science has followed, it has not led Engineering. It is the intimate

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association of the two which is the foundation of all industrial progress. The war of the microbes, the latest development of biology, is a consequence of sanitary requirements. Our knowledge of the diffusion of molecules and the solution of solids has sprung from the investigation into the mechanical properties and constitution of iron and its alloys; and the disturbances of the æther are becoming familiar through the practice of the so-called wireless telegraphy. Facts are derived from accident, observation, or practice; laws are the result of research. Engineers have always appreciated science up to the hilt; but they wish that its special votaries were less dogmatic and more modest.

The fathers of our profession, whose names you see emblazoned on our walls—Smeaton, Cort, Watt, Telford, Stephenson—acquired their science by their own researches, at a time when professors were largely teaching nonsense, and text-books were full of errors. We however acknowledge our indebtedness to pure science by giving the place of honour over this chair to Newton, and by adding the name of the most accomplished experimenter of the age, and the clearest but most modest expounder of his own famous discoveries, Faraday. I had the great satisfaction last Friday of presenting to the Vice-Chancellor of the University of Cambridge an illuminated address from this Institution, congratulating our Honorary Member, Sir George Gabriel Stokes, on attaining the jubilee of his professorship: a luminary in pure science, ranking with those two great masters who have established and taught the principles that we practise. Of the three men who have been raised by our Sovereign to the Peerage for their scientific attainments, we claim two, Kelvin and Armstrong, on our Roll; while Lister, who belongs to the nation, is also an Honorary Member of our Institution. In this class of Members we are proud to enrol also another peer, Lord Rayleigh, who, if he had not inherited that rank, would certainly have earned it by his grand scientific work—work so accurate and so reliable that it has secured the faith of the British electrician.

The practice of the engineer as the great civilizer has been well eulogised by our distinguished Honorary Member, Lord Salisbury. The engineer not only follows immediately the military conqueror, but he sometimes even precedes the civil pioneer. Mr. Cecil Rhodes is opening up Africa by the "wonder-working wire;" in a few months there will be an unbroken line of telegraph from Cape Town to Lake Tanganyika. Peace and goodwill are messages thus distributed without fire, bloodshed, or famine.

Before you disperse to your different Sections, to discuss the

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various questions allotted to you, I venture to allude to certain matters which cannot well be discussed in public, but which may form the subject of conversation among us.

The Lord Chief Justice's Bill for the suppression of illicit commissions is one welcomed by every member of this Institution; and it is most gratifying to find that no suspicion of improper practice has been adduced against our profession. At times however we do hear of a treacherous border-ground between consultation work and contracting, which is a pitfall to be avoided and to be surrounded by danger-signals. Occasionally again, fortunately rarely, we find the diploma of the Institution converted into an advertisement; this the Council strenuously protest against, in the best interests of the entire body.

The examination system, introduced just at the epoch of our first Conference, has proved a most unqualified success; and it has been welcomed by none more than by those who undergo its troubles. During the last Session, 107 Candidates passed the Associate Membership examination, in addition to 31 who qualified by passing exempting examinations elsewhere, and 65 who satisfied the conditions of election by theses. Further 53 passed the Institution examination for Studentship, whilst 167 qualified in that respect by passing various recognized Examinations. Thus we added 423 new names to our roll, all of whom satisfied the examination standards. The Council feel that the system of examination has enhanced the intrinsic value of the diploma of the Institution, and that it has added materially to the dignity and responsibility of the profession. This diploma has become so valuable and so necessary to the practising engineer, that occasionally would-be practitioners improperly assume the title of member or associate. Fortunately criticism is too wide-awake, and the public interest too well served by all who are jealous for the prestige of their profession, to permit deceptions of this kind to escape speedy detection.

The position of engineering has rendered it necessary for all new Universities, and especially for the Imperial University of London, to form a faculty of engineering; but the Council of this Institution have deprecated the idea of conferring degrees in engineering. Every engineer must acquire a knowledge of the scientific principles and the mental tools, which form the bases and aid the operations of his profession; but only by becoming an expert in its practice can he be an engineer. Examination can test the former qualification alone; and this is what we have introduced. Practical training is not a matter amenable to examination. Hence we

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consider that degrees in science are quite sufficient to signify the successful completion of a University career, which should be strictly scientific; and that the diploma of the Institution should be the criterion of that professional qualification which is the result of practice alone. And here I may mention that there is a tendency observable to avoid the condition that those admitted into our junior ranks shall be persons who are or have been *bonâ-fide* pupils of corporate members of the Institution. Further, no one can be said to be regularly educated as a civil engineer, unless he has passed through the ordeal of the training to be acquired in the workshop and the drawing office. It would be well, for the comfort of the Council, if those who rather lightly, and sometimes thoughtlessly, sign forms for election, would first enquire whether the conditions printed on the back of every form were properly complied with.

Let us sincerely hope that this Conference of 1899 will be as successful, as pleasant, and as fruitful, as that which took place in May 1897.

At the meetings of the various Sections, which were held on the mornings of the 7th, 8th and 9th June, 39 notes were read introducing subjects for debate, and in the afternoons of those days visits were made to 17 engineering works, in respect of which 2,150 tickets of admission were issued in response to the applications received from members and students.

A record of the topics presented for consideration at the meetings is contained in the notes [1] given on the following pages, references being made to the various journals in which reports of the proceedings may be found.

[1] The full text of the notes, together with a complete report of the discussions, may be seen in the Institution Library.



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NOTES INTRODUCING SUBJECTS FOR DISCUSSION.

SECTION I.—RAILWAYS.

7 JUNE, 1899.

# "What is a Light Railway, and what Circumstances should govern the Gauge?"[1]

By ARTHUR CADLICK PAIN, M. Inst. C.E.

A light railway might be defined as a railway constructed to suit the class and volume of traffic likely to be conveyed thereon, having either the standard 4 feet 8½ inches gauge of Great Britain, which is fast becoming the standard gauge of the world, or one of the numerous narrower gauges, such as 3 feet 6 inches, or the metre-gauge of 3 feet 3⅜ inches, or 3 feet, or 2 feet 6 inches, or 1 foot 11½ inches, or even only 1 foot 3 inches. The last is believed to be used only in works, and is in no case authorised on lines for public traffic.

The advantages of a narrower gauge than 4 feet 8½ inches may be taken for granted, as regards economy in first cost, even in an easy country, and much more so in a rough, hilly, or mountainous district; but it is not easy to see the advantages of so many variations. Attention has been drawn again and again, but without much avail, to the desirability of standardizing these smaller gauges, and making them, say for the sake of argument, 3 feet and 2 feet. The difference in first cost between lines of 3 feet 3⅜ inches and 3 feet, and between 1 foot 11½ inches and 2 feet, is small; the advantages of uniformity are great. Manufacturers of rails and fastenings, switches and crossings, girder bridges, iron station-buildings, locomotives, carriages of three classes, and goods and mineral trucks of various kinds, would construct them to more uniform patterns, thereby reducing considerably their first cost and the cost of repairs.

Wherever there is a great main-line railway, small towns and villages desire to be given the advantages of closer communication; and it must be better to have only two gauges on the one system

[1] *The Engineer*, vol. lxxxvii. p. 562; *Engineering*, vol. lxvii. pp. 733 and 753; *The Electrical Review*, vol. xliv. p. 965.

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than specimens of a greater number. In a large number of places the narrower gauge would lead to the development of the locality, and justify the subsequent change to a wider gauge, when everything but the fixed structures could be removed to some other district requiring similar development. Even of the fixed structures, parts might be removed, such as girders of bridges; and certainly some of the station buildings could be so constructed as to be removable if necessary. It is a mistake to try to construct a light railway of narrow gauge so that it can subsequently be altered into a full gauge by laying down a heavier permanent way: except in an easy country, and then only as regards the width of land taken. If a 2-foot gauge is decided upon, the permanent way should be laid suitable in all respects for that gauge only, and no attempt should be made to construct it as a kind of cross between a turnpike road and a footpath. The standardizing of narrow gauges to two widths should lead to the development of a mileage on light-railway lines greater than is at present thought to be probable.

From the military point of view, as well as the commercial, it is highly desirable that the War Department should be able at the shortest notice to obtain materials and stock for shipment to any part of the world, for laying down a lighter class of railway than that of the ordinary gauge. The standardizing to two narrow gauges would largely aid in this object, and would enable the officer in command of an expedition to follow up the advance of his troops by a light railway for providing them with the necessaries of life and munitions of war.

"Time" is now becoming more and more the "essence of the contract," to use a specification phrase; and anything which will enable civil or military operations to be conducted with rapidity and certainty is of national importance. The fact of large orders for bridge-work, locomotives, carriages, &c., having recently been sent to manufacturers in the United States, has been owing mainly to their ability to ensure prompt delivery, if their own types were accepted; and points to the necessity for standardizing gauge and stock in this country. This is a matter that requires full investigation before any decision is arrived at. It is to this Institution that engineers all over the world look, to set on foot such enquiries; and one object of the writer is to express the feeling of those who have the deepest interest in the matter, and their hope that the Council will take such steps as they may think desirable for obtaining the necessary information.



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# "Mountain Railways." [1]

By CHARLES ASSHETON WHATELY POWNALL, M. Inst. C.E.

As the lowlands on the earth's surface become more and more occupied by railways, the problem of extending these into or across mountain ranges assumes a constantly increasing importance; but, in approaching its solution, the question has first to be asked, what is a mountain railway? Are there to be included in this discussion the small lines which are so frequent, especially in Switzerland, for the conveyance of a car-load of tourists to an hotel? or should these be excluded, and only the more important lines be considered, with train-loads of at least 50 tons and gradients not flatter than 1 in 40? With the time at disposal it will probably be best to adopt the latter course, and omit mention of the smaller lines.

It is then found that the heavier lines divide themselves naturally into two groups. The first is represented by the passage of a main line over a range of mountains intervening between its two extremities; and the second by the penetration of a branch line into a mountain region, either for conveying tourists uphill, or for bringing ores and minerals downhill. In some places, as at the Harz and the Eisenerz, both purposes are served.

Then follows a further subdivision as to the method of construction and of traction: that is, whether the line is originally laid out for working by ordinary locomotives, which use adhesion only; or whether special engines are employed, working with rack and pinion, either on the Riggenbach or the Abt system, thus shortening the route by steepening the gradient; or finally, in extreme cases, whether the same object is accomplished by breaking up the train into sections, each of which is sent separately up an inclined plane by rope haulage, as on the São Paulo Railway in Brazil. Such departure from ordinary working by adhesion only is often justifiable on the score of expense, when dealing with branch lines; it can hardly ever be so, when it involves crippling a chain of through traffic by the insertion of a link on a special system, for the weakness of that link in traffic capacity will surely weaken the whole chain.

On the more recent lines it is usual to reduce the gradient when passing round curves: so that the curve resistance, together with that due to gravity, shall not impose on the engine a heavier task

[1] *The Engineer*, vol. lxxxvii. p. 562; *Engineering*, vol. lxvii. pp. 733 and 753.

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than that due to the ruling gradient on straight sections. For rack lines with heavy loads the ruling gradient should not be steeper than 1 in 20, nor on adhesion lines should it be much, if at all, more than 1 in 40. In order therefore to keep the gradient down to these figures, it often becomes necessary to increase the length of the ascent by development curves, of which perhaps the finest examples are to be found at the St. Gothard.

One of the most interesting questions for the engineer is the extent to which he is justified in increasing capital expenditure by thus adding to the length of the line, in order that the reduced gradient may enable larger and more profitable loads to be taken over it. The increased interest to be paid on a larger capital has to be weighed against the probable gain in revenue from heavier trains. So also must it be considered whether it will not eventually pay best to form earthworks and tunnels for a double line of road in the first instance, even if the traffic at first in view seems hardly likely to warrant the expenditure. The initial expense of a wider formation is far from doubling the original cost of the works; and if the formation has to be widened subsequently, it may involve the risky as well as expensive process of cutting further into precipitous slopes, while traffic is passing below them.

With the usual single line of road, stations, which become passing places, should be systematically and evenly distributed; for, as the speed of ascent on 1 in 40 is often not more than 8 or 10 miles an hour with a heavy load, it is impossible to run many trains daily, if the distance between passing places is such that a considerable time must elapse before the line between them is clear. Regardless of this consideration, stations are sometimes placed irregularly to suit some hamlet or road which catches the eye on the plan, but has no value for traffic. Such an occurrence happened on the Gotemba inclines in Japan, as laid out by native engineers; for during the war with China the military trains from Tokio, as they ran up the incline of 1 in 40 between Oyama and Gotemba, had 6½ miles to cover before the line was clear for the descending train, so that about an hour elapsed before the next upward-bound train could follow; and the traffic capacity of the line, for sending soldiers readily to the front at a time of national emergency, was thus largely diminished.

In the estimation of traffic it is necessary to consider not only the weight which can be hauled, but the speed at which it moves; for the latter directly affects the number of trains which can be run, especially on single lines, where the up and down trains have to pass alternately over the same metals.

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Where the ground permits of alternative routes for an ascent, it is useful to work out, by the method of equivalent lengths on the straight and level, the traffic and haulage features of each. The result of this calculation, taken in connection with the estimated cost of the respective routes, will enable an opinion to be formed as to the value of each scheme relatively to the outlay involved.

Where there is a choice of gauge, the broader it is, the better; for this enables engines with wider fire-boxes and larger heating surfaces to be used. Where great power is required, the locomotive builder is often cramped in his design by being tied to too narrow a gauge.

The question of adequate brake power on the descent is as important for safety as is that of sufficient tractive power on the ascent for making the line profitable. For this object the air-brakes now in general use are most serviceable on adhesion lines; while on the rack railways carrying heavy trains on inclines as steep as 1 in 12, the employment of the rack cylinders as air-brakes on the descent, and the grip of the pinion in the rack, furnish useful auxiliaries.

Each railway presents a separate problem, and no general rules can be laid down; but the above are some of the most important points which require attention.

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## "The Advantage or Disadvantage of Uniting the Lock and Block Signalling Appliances of Railways." [1]

By Alexander Ross, M. Inst. C.E.

In opening a discussion on this subject, it is desirable to consider shortly the interlocking of points and signals, and the block system as worked by means of electric telegraph instruments.

A railway is naturally divided into sections by the stations provided to accommodate the traffic at various places along the route through which it passes; and these, with some supplementary places where the distances between stations are too long, form convenient divisions of the line for controlling and working the traffic. A signal-box is placed at the end of each section, and in it is fixed the "locking frame" containing the levers for working the

[1] *The Engineer*, vol. lxxxvii. p. 563; *Engineering*, vol. lxvii. pp. 733 and 753; *The Electrical Engineer*, vol. xxiii. p. 788.

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points and outdoor signals; and for a railway with two lines of way (one up and one down) there are also provided inside the signal-box two electric bells and four block telegraph instruments, one bell and two instruments for regulating the traffic in each direction. In addition the signal-boxes are frequently in telephonic communication with each other. Each division of the line becomes a block section; and by this means the line is worked on what is known as the absolute block system, which is briefly a system whereby a definite interval of space is now maintained between all moving trains, instead of an interval of time, as used to be the case in the early days of railways.

Two modifications however of the above rigid method are allowed under certain circumstances. One is known as the permissive block system, by which, under strict caution arrangements, more than one train at a time is admitted into a section; this is chiefly applicable to the running of goods trains. The other modification is known as "section clear but station or junction blocked;" whereby a succeeding train, moving towards a junction where it will diverge from the line on which the preceding train is travelling, is allowed to proceed slowly to the home signal of the box at the further end of the section; but before entering the section it is a condition that the signalman at the entering end must bring the train to a stand, and inform the engine-driver verbally of the state of the line ahead.

Every station is provided with the usual outdoor semaphore signals, generally for each line of way: namely, a distant, a home, and a starting signal; and, where shunting takes place beyond the starting signal, an advance starting signal is added. There is also the usual complement of subsidiary signals, depending upon the number and nature of the sidings connected with the main line. The points and outdoor signals are worked by the levers inside the signal-box; and the movements of these are controlled by the locking in the frame, and are guided so as to lock and interlock in such a way as to produce a definite sequence of events, and to ensure that the positions of the points must be in harmony with those of the outdoor signals, and that, on the line being made for a passing train, the points must be in their right positions before the corresponding signals can be lowered.

Each block instrument in the signal-box usually consists of a case having a dial in front, provided with a needle, which normally hangs vertically on the dial; in this position it indicates that the line is closed, and the words "line blocked" are exhibited immediately underneath the needle. At the top right-hand corner are

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the words "line clear," while at the top left-hand corner are the words "train entered section." Each instrument is provided with a handle; and the block is generally worked on the three-wire system. On the handle being moved to the left, a positive current flowing diverts the needle to "line clear;" similarly, on the handle being moved to the right, a negative current diverts the needle to "train entered section." Regulations, with a code for working the absolute block telegraph, have been agreed to by the various railways, and are in general use.

The method of passing a train along the line is as follows. The signalman A, wishing to pass a train forwards to the signalman B in advance, calls attention by giving one beat on his bell, which B acknowledges by repeating it. A will then forward to B the signal "is line clear?" by giving a number of beats on his bell, varying with the class of train coming. The signalman B, having ascertained that the line is clear between A and B, will repeat the bell signal to A, and will peg over the needle of his own dial to "line clear," indicating thereby that A may allow the train to proceed. A will then give the signal "train entered section" on both his bell and dial, which B will acknowledge, and will peg over his dial signal to "train entered section." B then goes through a similar course with the signalman C next in advance of him; and so on throughout the line. As soon as the train has passed B, he will give the signal "train out of section" on his bell and dial to A; and, when this has been acknowledged, he unpegs his instrument, thereby allowing the needle to assume its normal vertical position. If these operations are properly carried out, it is quite impossible for two trains to be in one section at the same time.

The locking apparatus, and the levers working the points and outdoor signals, in themselves as perfect as human ingenuity and good workmanship can make them, are worked independently of the inside block telegraph signals, the only connecting link between the two being the signalman who actuates both; and there is no physical obstacle to prevent him, in a moment of forgetfulness, from giving outdoor signals in conflict with his indoor block instrument. Therefore the question raised for discussion is, whether it is desirable or not to unite and combine the two systems, either mechanically or electrically, into one complete system, in such a way as to ensure, not only unity of action at one signal-box, but also with the next box in the rear and in advance.

The conditions which should be fulfilled by an efficient "lock"

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and "block" arrangement may be stated as follows. The rear signalman A should not be able to lower his outdoor signals, or allow a train to enter the section in advance of him, until the signalman B in advance has given him the necessary permission by unlocking the starting signal. The rear signalman A, having received permission from the advance signalman B to allow a train to enter the section, and having lowered his signals, and the train having entered the section, should be compelled to put his starting signal back to danger; and the lever working the same, on being thus put back to its normal position, should become locked there in such a way that it cannot be used again without the permission of the signalman B in advance. This locking of the starting lever should free the home signal of the rear signalman A, so that a second train may be brought forward to his starting signal; and, for the protection of this second train, his home signal should be placed to danger and locked there, before a third train can be offered to him. When the first train has arrived at the signalman B in advance, and has passed his home signal, and the signal "train entered section" has been received from the signalman C still further in advance, the signalman B must put his own home signal to danger, before he can give "line clear" to the signal-box A in the rear for a second train. This requirement applies when the section is from starting signal A to home signal B; but if the section is from starting signal A to starting signal B, the same requirement will apply to the latter.

The arrangements should be such that shunting operations, or placing a train in a refuge siding, or turning a train back, or slipping a carriage, may take place at any of the stations without break of continuity for the through traffic. The methods employed should be as simple as possible, and such as can be applied to the existing locking frames and block telegraph instruments; and should be actuated from within the signal-boxes in the ordinary working, and without additional electric wires. It should also be possible by the ordinary operations of the levers to cancel the permission already signalled for a train, without having to resort to special keys or releasers. While long-distance locking must be performed by an electric current, the moment this has been effected the lock should be secured by a mechanical movement, the current should be cut off, and all succeeding movements should be mechanical. The use of treadles should be reduced to a minimum, and by preference should be avoided altogether. The arrangement should be applicable, not only to "absolute block working," but also to "permissive block working," and to the

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warning method known as "section clear but station or junction blocked;" and should be equally applicable to single lines and to double lines of way. It should be possible to apply the system effectively to particular portions of railways, such as junctions, or the outlets of loop-lines, without disturbing the ordinary working of the other portions. The arrangements should be such that, by the provision of visual signals, the stoppage of a train proceeding under the warning method for verbal instructions from the signalman to the driver would be rendered unnecessary.

The question at issue, however, is the advantage or disadvantage of uniting the lock and block signalling appliances of railways. If the conditions enumerated above are secured, the advantages appear obvious, of which the principal may be stated to be as follows, namely:—

1. It is impossible for the outdoor signals to be at variance with the indoor block instruments.

2. The rear signalman is compelled to forward a train to the man in advance.

3. The advance signalman is unable to accept a second train before the first has passed clear out of the section.

4. Absolute protection is secured for the train while in the section.

5. It is impossible for the rear signalman to forward any train in error.

6. The co-operation of three men is necessary in signalling every train.

7. A train can be passed more quickly out of the section by adopting visual signals under the warning rule, instead of stopping it and communicating verbally with the driver.

As to the disadvantage, this is somewhat difficult to define. It is alleged that, with a long section extending from starting signal to starting signal, delays and unnecessary complications may be caused when shunting operations are being carried on at a station.

It has been the Author's aim to state this important subject in as concise a manner as possible, and in such a form as he trusts will provoke discussion. There are a number of engineers throughout the country who have made a special study of the subject of uniting the "lock" with the "block"; and it is hoped they will give their opinions freely, and that this discussion may lead to practical results.

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## "The Various Systems of Railway Fog-Signalling."

By WILFRID SWANWICK BOULT, Assoc. M. Inst. C.E.

(*Abstract.*)

Schemes of fog-signalling were classified as signals on the road and signals on the engine or train, with seven subdivisions of each group; the plan which at present held the field was that of employing men on the road with detonators, lamps, and flags. It was urged that a list of requirements should be formulated, that plans should be submitted, and that a thorough practical trial should be made of any method considered sufficiently promising. Instead of taking the absence of an explosion to mean "line clear," the positive signal required in clear weather was much more necessary in fog. As a basis for discussion a list of requirements was submitted, in which were included the following, with several others:—certainty of action, simplicity of construction, durability, protection from accident, easy renewal, small attention, low cost and maintenance; signals to be given in engine-cab or other vehicle of train, to be independent of speed, and to be applicable for starting; two distinctive signals, for danger and for line clear; distant and home signals to be distinguished; and the apparatus to be unaffected by weather. These desiderata were stated to be met by the Author's plan of magnetic signalling without contact, which had proved successful in working on a Great Northern express engine at maximum speed. With a miniature semaphore on the engine the arrangement recommended was that it should always show the last signal received; and that a bell should ring all the time the signal was on, until stopped by hand in such a way as not to interfere either with the semaphore or with the next ringing of the bell for the next signal.

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[1] *The Engineer*, vol. lxxxvii. p. 568; *Engineering*, vol. lxvii. pp. 735 and 863.

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9 JUNE, 1899.

## "The most Expeditious Method of Relaying the Railways of this Country, involving the least Interruption of Traffic, having regard to Safety and Economy."[1]

BY HARRY FOOTNER, M. Inst. C.E.

In introducing this question, no detailed description of any system of relaying can be given within the prescribed limits. The Author therefore confines himself to classifying the methods of relaying, and to suggesting what appear to him to be the principal objects to be attained, and the circumstances that should be borne in mind in determining which method is most suitable under given conditions. His remarks will refer only to suburban and to main trunk lines.

In the compilation of a train service, when all other demands have been satisfied, an average allowance of time must necessarily be made for the interruptions and delays arising from the repairs and renewals of the permanent way and works; and even a further margin must be provided for contingencies. The regularly recurring operations so anticipated will comprise—signalling work, bridge and station reconstruction, mining subsidences, renewal of junctions and points and crossings, lifting and relaying the permanent way, &c. Although relaying does not cause one-half or even one-fourth of the total "train slackenings" due to these numerous works, it is nevertheless extensive enough to call for any amelioration that can be suggested. It is therefore obvious that such a division of repair and renewal work as will spread all these slackenings uniformly over the months of normal traffic, and will reduce them to a minimum when traffic is abnormally heavy, will conduce materially to the maintenance of a regular train service, and will be best for all concerned.

When putting in hand a long length of relaying, the question arises, what should be the maximum length of line to be taken up at one time? A little consideration will show that no more definite rule can be laid down than this: that the operation should not require any important train to run at slackened speed for so long a space as to render it impossible for it to arrive in time at the next stopping-place where it has some connection to make.

[1] *The Engineer*, vol. lxxxvii. p. 612; *Engineering*, vol. lxvii. pp. 799 and 826.

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All relaying requires:—

(1) A period of train "slackening," while preparing the old line for removal.

(2) An interval of "absolute block," while throwing out the old line and laying down the new.

(3) A further period of "slackening," while lifting, levelling, and straightening the new line, until consolidated.

These periods will be in different proportion, according to the method of relaying adopted; but the length of the "absolute block" interval (2), whatever it may be, must be so determined as never actually to *stop* an important train, and seldom to stop any other train whatever. In the interests of the traffic the engineer has to consider how he can reduce the "slackening" periods (1) and (3). Sometimes a line may with safety be denuded of a portion of its ballast, and of some of its keys and fish-plate bolts, while trains are running at their customary speed; but with an old and weakened road it is not prudent to permit the relaying foreman to trench upon the margin of safety to an extent which cannot be exactly defined beforehand, and which even in most careful hands may some day be carried too far, and result in disaster. All trains should therefore be slackened at the commencement of period (1), that is, as soon as the work of preparation begins; and should be similarly slackened all through period (3), that is, until it is seen that all sleepers are uniformly and solidly bedded, and the rails true in line and level.

The methods of relaying may be classified as follows:—

A. Gradually replacing old with new materials: such as turning the old rails out and the new rails into the old chairs; then withdrawing the old chairs with the old sleepers one by one, and replacing them with new chairs and sleepers.

B. Putting together all the new materials in one of the two following ways before removing the old line:—either (1) putting the new line together wholly outside of and parallel to the old line; or (2) interlacing the new line with the old, each of the new rails being 9 inches to 12 inches from the corresponding old rail. Finally slueing the new permanent-way into position, as fast as the old can be removed.

C. Clearing away entirely the old line, and preparing the sleeper-bed before putting the new materials together.

*Period* 2.—When the working intervals between trains are too short and infrequent to permit of the replacement at the desired rate of progress, single-line working must be adopted; or if the trains are too numerous night and day during the week for

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working single line satisfactorily, and no other diversion of the trains can be made, Sunday work must be adopted. Working single line for the whole or part of Sunday generally presents no traffic difficulty; and the length of new line that can be put in (bearing in mind the rules as to slackening) is limited only by the available number of platelayers, and by the amount of ballast that can be brought to the place when new ballast is required.

The cost of labour in relaying depends upon the following conditions, amongst other things:—

(1) The weight of the materials to be handled.

(2) The level at which it is considered necessary or desirable to place the new line.

(3) The relative quantity of old ballast to be thrown out and used again, and the quantity to be sent away and replaced by new.

(4) Whether day, night, or Sunday work.

(5) The extent to which the regular traffic interferes with the attending ballast trains.

(6) The relative number of skilled and unskilled men available.

(7) The degree of thoroughness of the work done at the time: good work is amply repaid later on by the lessened attention required in repairs.

The cost of relaying, however important in itself, is subservient to the necessity for executing the work in a manner that shall offer the least interruption to the regular train service. Even with the same method of relaying, the foregoing conditions vary to an extent that may cause one piece of relaying under unfavourable conditions to cost twice and even three times as much as an equal length where everything is favourable. On this account therefore it would be difficult to make any useful comparison of the cost of different methods without a large number of instances of each. The Author is of opinion that method A is more expensive in the long run than either of the others. Method B (2) may present the greatest advantages when the chairs have to be attached to the sleepers on the ground; and method B (1) is an expeditious way of executing the work during the "absolute block interval" (2), provided the embankments and cuttings are wide enough and sufficiently free from obstruction to allow of laying out the new material parallel to the old line. But he ventures to express the opinion that method C is best calculated to result in a good running road, and on this account is preferable for general adoption.

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# "Causes of Earth-Slips in the Slopes of Cuttings and Embankments of Railways, and how to Prevent or Remedy them."[1]

By Robert Elliott Cooper, M. Inst. C.E.

In presenting this Paper for discussion the Author does not pretend that it in any degree exhausts this important though ordinary contingency of railway construction. It is intended only to form a basis for the expression of the opinions and experiences of engineers who in their ordinary practice have had to deal with earth-slips.

*Slips in cuttings* are occasioned by a greater diversity of causes than slips in embankments. One of the chief causes of the former is water percolating from the surface through the more porous ground till a more or less impervious stratum is reached, when it forces its way to the face of the cutting slope, and thereby causes the mass above to slide forward. Many instances of this kind have been met with by the Author, especially in some parts of Yorkshire, and in the Isle of Wight. He finds a most effective way to prevent such a slip is to put in a deep drain along the top, at the back of the slope, and fill it in with dry stone. This drain should be connected with the side drains in the cutting by means of dry stone drains down the slopes, their distance apart being determined by the circumstances of each individual place.

Another common form of slip, in the coal-fields, is that caused by the line being cut through strata containing layers of rock lying at an angle steeper than 25 degrees, or even less. A slip of this kind occurred in a cutting about 40 feet deep. The layer of rock was cut through just above formation level, and the whole superincumbent mass gradually slipped down the face of the rock. Probably a strong toe wall would have stopped the movement; but as the material was required to fill up a station-yard, it was not thought worth while to incur the expense, as the cost of the extra land only was involved.

A cause of numerous slips, especially in deep cuttings, is the practice of driving a gullet right through, leaving the wings for months before trimming them back. It is far better to excavate the cuttings in lifts, and batter back the slopes at once, so that the upper part gets firmly set before the bottom of the cutting is

[1] *The Engineer*, vol. lxxxvii. p. 612; *Engineering*, vol. lxvii. pp. 799 and 826.

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taken away. In all ordinary cases deep stone drains built up the slopes have a good effect.

There are of course many instances where all ordinary methods of dealing with slips are unavailing. In Jamaica, where the Author has lately paid a professional visit, extensive slips have occurred, partly on account of the treacherous nature of the strata, and also owing to the excessive rainfall, 200 inches per annum, for which no efficient provision had been made. In one portion of the railway, where there was a series of cuttings on sloping ground, it was found necessary to divert the line for some miles, as the sides of the cuttings slipped in almost as fast as they were got out, and after two years it was difficult to imagine that any cuttings had ever been made.

*Slips in embankments* are chiefly of two descriptions: first, where the material composing the embankment slips; and second, where the surface of the ground, upon which the embankment rests, slips away on the underlying strata.

The former slip is often caused by the embankment being composed of material of different descriptions, such as rock, clay, and shale. Slip arising from this cause can generally be stopped by building dry stone counterforts up the slopes, and connecting these counterforts by dry stone pitching. In the construction of high embankments however, by far the best mode of forming them is by tipping in layers from 15 feet to 18 feet high, taking care to keep the lower layers of full width, so as to allow a cess when the next layer comes to be tipped. For the sake of appearance this cess can easily be trimmed off when the slopes are formed for soiling and sowing. It is a somewhat curious fact that in high embankments, made of mixed material such as is found in the coal districts, the natural slope is not uniform throughout its height; the top and bottom portions stand at about $1\frac{1}{2}$ to 1, or slightly steeper, whereas the centre portion generally takes a slightly flatter slope. This can be seen in many high embankments with which the writer is acquainted.

The second category of embankment slips is much more serious, and often entails great expense. Where the ground upon which the embankment will rest is of a wet and soft description, the most obvious and best preliminary step to take is to intersect the whole site with wide dry stone drains, varying in depth according to the nature of the ground. If below the soft surface a hard stratum is met with, at a depth say of 10 or 12 feet or less, great future trouble may be saved by cutting a trench of this depth along the site of the toe of the embankment, and filling it with stone

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as large as can be conveniently obtained. This plan was adopted with good results on one of the new lines constructed during the last few years in Derbyshire. On a long embankment about 75 feet high in Derbyshire, the plan of diagonal trenches filled with stone was adopted by the Author with the best results, only three small and unimportant slips having occurred.

In another place piles were driven along the toe of the embankment, with the idea of pinning the surface upon which the embankment rested to the hard stratum below; but this was not successful, as the embankment forced its way under the soft material, and lifted both it and the piles about 10 feet above its original level. This embankment would stand for months after being tipped to its full dimensions; and would then suddenly slip, and the slopes break away with a vertical drop of 8 or 10 feet. In order to stop the slip, which was on side-lying ground, many expedients were tried, including wide and deep trenches, filled with stone up the slope. Eventually the embankment was completed by tipping many thousand cubic yards of ashes into it. Since the ashes were used, no further trouble has been experienced.

In many instances a good plan is to burn the lower part of the slip, so as to form a cushion for the material above.

## "Economy in Handling and Transport of Minerals." [1]

By CHARLES DE NEUVILLE FORMAN, M. Inst. C.E.

The economical handling and transport of minerals is a subject which should command the best attention of the engineering profession. The magnitude of the work that has to be performed in this country every year in connection with this branch of trade almost surpasses comprehension. As far as can be ascertained, the total quantity of raw material in the shape of mineral produce in the United Kingdom, which has yearly to be handled and transported in some form or other, amounts to not less than 260,000,000 tons; so that every penny spent per ton upon the handling and transport represents rather more than £1,000,000 sterling.

By far the most important product of course is coal, of which upwards of 200,000,000 tons are raised, at an average cost of 5*s.* 5*d.* per ton. Iron ore ranks next, amounting to fully 16,000,000 tons,

[1] *The Engineer*, vol. lxxxvii. p. 613; *Engineering*, vol. lxvii. pp. 800 and 827.



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raised at a cost of 4*s.* 6*d.* per ton; and, in addition to the iron ore raised, fully 6,000,000 tons are imported at a cost of 14*s.* 9*d.* per ton. The other minerals produced in large quantities are: limestone and chalk, nearly 15,000,000 tons; clay nearly 13,000,000 tons; sandstone nearly 5,000,000 tons; and salt, granite, sand, and gravel add another 10,000,000 tons to be handled and transported.

Year by year more attention is being paid to the important task of handling this vast amount of material; and collieries are now fitted up with expensive machinery for drawing, screening, washing, and loading. The most important means of transport are the railways. Fully three-fourths, or 153,000,000 tons, of the coal produced is transported by rail, of which 65,000,000 tons are shipped. It would be interesting to know what money is absorbed in this service. The only figures the Author has been able to get indicate that the average value of the coal shipped is nearly 9*s.* per ton, or 3*s.* 7*d.* higher than the cost of raising it. If this fairly represents the difference between coal at the pit and coal in the market, it appears as if £35,000,000 were absorbed in getting coal into the market after it has been raised. It is probably not possible to ascertain how much of this goes in railway carriage; but it is certain that a large sum must be spent in this service. If one-fourth of the sum is allotted to the cost of hauling, and if it is assumed that the average load is 8 tons per wagon, there are 19,125,000 wagon-loads carried in the year at a cost of £8,750,000. Such figures must impress engineers with the great importance of economy in wagon design.

The standard clearing-house wagon used in this country tares about 6½ tons for a 10-ton load, and, according to common practice, the wagons return empty. Thus 12½ tons of dead weight have to be hauled for every 10 tons of paying load, so that more than £4,500,000 a year are spent in hauling dead weight. The tare of wagons used in the United States is about one-third of the load they are designed to carry. If the paying and the dead load were in the same proportion in this country, there would apparently be an annual saving of fully £2,000,000 in railway transport. Proposals have recently been made to construct wagons of much larger capacity than any at present in use in this country; but, in view of existing sidings, the load upon the axle and the flexibility of the wheel base must now be most important factors in determining the economical design. In the Author's opinion, four-wheeled bogie trucks, with an axle-load of 8 tons to 9 tons, will be found in the end to answer best all the require-

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ments of trade; and at the same time they afford scope for economy in design. It is a subject to which attention may be advantageously directed; but the British system of following hard and fast rules, and giving no encouragement to the introduction of novelty in design, does not stimulate the inventor.

A great deal of attention has been paid by engineers in recent years to different methods of shipping coal. In modern practice the appliances most advocated for loading are the high- and low-level hydraulic hoist and the crane; while continuous transporting belts are sometimes preferred. Some remarkable evidence was given lately to a Parliamentary Committee as to the actual working of hydraulic cranes in Glasgow Harbour. These cranes admittedly could not handle more than twenty wagons an hour, yet the average shipment of five cranes was given at 305,212 tons per crane per annum; whereas the average of the Barry Dock high-level shoots was given at 288,000 tons, although the capacity of the tips was stated to be one wagon per minute. It was admitted however that the labour involved with the cranes was as seven to three in favour of the hoists; but this might be obviated by properly-designed feeding sidings, which do not exist at Glasgow. Such sidings constitute a most important element in the economical handling of shipping traffic. The best loading appliances may have all their advantages neutralised by want of properly designed receiving and feeding sidings. The advantage of well-arranged and properly designed railway sidings in the transport of minerals does not receive the attention that it deserves. Much loss of time is involved in shunting sidings, where provision is not made for keeping clear of the main line; and where marshalling yards or staging sidings are introduced, the consideration of how the sidings can be worked with the least delay to the rolling stock is often neglected. Such inconvenience and delay add materially to the cost of handling and transporting minerals.

Next to coal, the handling and transport of iron ore calls for the engineer's attention. The supplies of ore coming from abroad to this country are steadily increasing. The import to the Clyde has risen from 318,000 tons in 1886 to 1,295,000 in 1896. Under such conditions our supremacy as steel makers can be maintained only by using all means and appliances which tend to reduce the price of the raw material we have to purchase.

Where steel works are situated inland, great difficulty arises from the irregularity with which the supplies arrive from abroad. Many works are unable, and most are unwilling, to provide storage for large quantities of ore. As a consequence, the railway



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companies refuse to allow their trucks to be filled and to lie under load, and the discharge of the boats is stopped. The demurrage on the ships and wagons, and the cost of discharging at the works before the ore is wanted, all involve loss of time and money; and here again the skill of the engineer may be advantageously applied. Where convenient ground can be got in the neighbourhood of the port, the erection of suitable stores into which the vessels' cargoes can be discharged, and from which the railway wagons can draw regular daily supplies, would at once remove all difficulties; but it is essential to the adoption of this plan that the engineer's designs be such that the cost of discharging, weighing, storing, and loading, shall be so much less than the amount now wasted as to justify the necessary outlay of capital. One shilling a ton saved on the cost of importing ore represents roughly two shillings a ton on the price of the steel into which it is manufactured.

Consideration of the figures above given must convince everyone interested of the importance of engineers applying their minds to this subject, and of the advantages which must arise to the community from any economy they are able to effect in the handling and transport of minerals.

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## Section II.—HARBOURS, DOCKS, AND CANALS.

7 June, 1899.

# "The Discharging and Reloading of Large Steamers." [1]

By William Henry Hunter, M. Inst. C.E.

*(Abstract.)*

At the close of the nineteenth century the commercial supremacy of this country was being challenged by a host of rivals, and competition on every side was most keen. Arising out of this fact was the recognised importance to merchants and manufacturers of moving large masses of commodities at the lowest possible unit rates; and one item in the developments due to the recognition of this principle was the extraordinary increase recently effected in the size of steamers.

While 15 years ago a steamer of 5,000 tons dead weight was looked upon as a leviathan, to-day steamers of from 15,000 to 20,000 tons were in constant use, and the ordinary cargo steamers ranged from 8,000 to 12,000 tons dead-weight capacity. In order to load and discharge these steamers with the requisite rapidity, an entire change had been needed in the methods formerly in vogue; and novel appliances for dealing with cargoes, and extensive storage accommodation, had been rendered absolutely necessary. It was shown that the expenses and charges on a steamer of a capital value of say £90,000 amounted to not less than £100 sterling a day. Such a vessel, trading between North America and Great Britain, would make twelve round trips per annum, and would therefore be twenty-four times in dock in the course of the year; hence one day saved in the process of discharging and loading at the end of each voyage would mean a reduction in the steamer's expenses of £2,400 a year, or 2·66 per cent. upon her capital cost. An account was given of the miscellaneous character of the cargo of such a vessel, which would comprise live cattle on the upper deck, timber, perhaps cold storage, grain, etc., all the different items having to be specially dealt with in close proximity to the loading place. In order to describe briefly the modern methods of working, the

[1] *The Engineer*, vol. lxxxvii. p. 564; *Engineering*, vol. lxvii. pp. 736 and 754.

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Author gave an account of the system in operation at the Manchester docks of the Ship Canal, and explained the special arrangements made to deal with each class of commodities—cattle, goods, timber, grain, etc.—in the process of unloading.

## "The Length, Width and Depth, and the Shape and Mode of Construction of Locks and Entrances and Graving Docks, having regard to the Increasing Sizes and the Shapes of Vessels." [1]

By Robert Cope Hardy Davison, M. Inst. C.E.

The question which the Author has been asked to introduce for discussion presents a problem of great and varying difficulty; and its correct solution will prove of considerable financial benefit to any dock undertaking, on which engineers may be called upon to advise. It is a subject that can be treated only generally, as each trade and district have different requirements, and time alone will disclose the size of the vessels of the future.

As docks are made for ships, and not ships for docks, the present requirements of the Merchant Navy should first of all be glanced at. The cause of the somewhat sudden increase in the average size of sea-going vessels was dealt with by Sir William White in this year's inaugural address to the Institution of Mechanical Engineers. The change from sail to steam, and from iron to steel; the great extension of mechanical labour-saving appliances in the construction and working of ships; the vast improvement of marine steam-engines and boilers; hydraulic, electric, and pneumatic power; and refrigeration—were all shown to have had part in this increase.

A few of the giants that now ply upon the principal ocean highways of the world are mentioned in the Table on the following page. Of these it was the s.s. "Milwaukee" which, having struck on a rock last autumn on the coast of Aberdeen, had her forward section cut away so cleverly by the aid of dynamite, while her stern division, including the engine-room, was floated into deep water and towed to the Tyne, where she has been rebuilt and relaunched. With regard to the North Atlantic

[1] *The Engineer*, vol. lxxxvii. p. 564; *Engineering*, vol. lxvii. pp. 736 and 754.

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| Steamship. | Gross Tonnage. | Length. | Breadth. | Draught. |
|---|---|---|---|---|
| *North American Liners.* | Tons. | Feet. | Feet. | Feet. |
| Kaiser Wilhelm der Grosse | 14,349 | 627·4 | 66·0 | 27·0 |
| Lucania | 12,952 | 601·0 | 65·2 | .. |
| Kaiser Friedrich (recently dry-docked at Tilbury) | 12,481 | 581·7 | 63·9 | .. |
| Pretoria | 12,250 | 560·0 | 62·0 | .. |
| St. Louis | 11,629 | 535·5 | 63·0 | .. |
| St. Paul | | | | |
| Oceanic (not yet finished) | 17,000 | 704·0 | 68·0 | 32·5 |
| Deutschland (not yet finished) | 16,000 | .. | .. | .. |
| *Cape Liners.* | | | | |
| Briton | 10,248 | 530·0 | 60·3 | .. |
| Carisbrook Castle | 7,626 | 485·0 | 56·0 | .. |
| *East Indian and Australian Liners.* | | | | |
| India | 7,911 | 499·9 | 54·3 | .. |
| Ophir | 6,910 | 465·0 | 53·4 | .. |
| Polynesian | 6,506 | 482·3 | 49·2 | .. |
| *South American Liners.* | | | | |
| European | 8,194 | 475·9 | 55·0 | .. |
| Orizaba | 6,298 | 460·0 | 49·3 | .. |
| Danube | 5,946 | 420·0 | 52·0 | .. |
| *General Cargo Vessels.* | | | | |
| Algoa | 7,575 | 455·0 | 58·0 | .. |
| Milwaukee | 7,317 | 470·0 | 56·1 | 26·0 |
| *Cable Ship.* | | | | |
| Silvertown | 4,935 | 338·0 | 55·0 | 28·0 |

Liners, it would be rash to prophesy to what size they may attain; the depth at New York bar is now 30 feet, and 34 feet is being aimed at; and Liverpool has 26 feet at low water of spring tides, and is being improved every day. A new fleet for the Cape trade is spoken of, with vessels 487 feet long, 58 feet beam, and a draught of 28 feet loaded and 21 feet light. The Suez Canal regulates the draught of vessels trading to the East; it must not exceed 25 feet 7 inches at the present time. The South American trade is to some extent governed by the depth of the River Plate, which is under 20 feet. The large cargo ships are governed by all the foregoing facts, as well as by the shipbuilders and Lloyd's Committee. The large cargo ships of packing-case design the Author thinks cannot be said to be a success from the ship-owners' point of view, which is not always that of the shipbuilders. They are unwieldy and expensive to maintain, slow and difficult to

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steer when unloaded or with part cargo, and the premium asked for their insurance is believed to be higher. In his opinion they are not a class of ship that has come to stay; and he considers vessels carrying 6,000 to 7,000 tons of cargo are likely to come out triumphant in the end. A cargo vessel over 500 feet long cannot be found.

Among the vessels above mentioned are some that do not fly the British flag; and no one who is familiar with British ports can have failed to notice an increase in that respect during the last two years. Most of the sailing vessels have already passed into foreign hands, and there are rumours of some steamship companies following suit. It speaks volumes for the enterprise of the British ship-owner that he has held his own so long, with one law for the British and another for the foreign ship in a British port, and all in the usual manner to the advantage of the foreigner. How differently these things are managed abroad—no light dues, a rebate on port dues, a bounty on tonnage, a bonus on mileage: but not for the British ship.

The following are the dimensions of the entrances to some of the chief ports. Liverpool, 100 feet wide by 600 feet long; but vestibule basins to act as locks are in contemplation, 520 feet by 1,150 feet, with entrances 100 feet wide and 32 feet deep. London, Royal Albert, 80 feet by 550 feet; Tilbury, 80 feet by 700 feet; Hull, 85 feet by 550 feet; Newcastle, 100 feet by 320 feet; Belfast, 100 feet and 80 feet; Barrow, 80 feet and 100 feet by 700 feet; Leith, 60 feet by 350 feet; Manchester Ship Canal, 80 feet by 600 feet; Plymouth, 80 feet; Cardiff, 80 feet by 600 feet, and large new dock in course of construction, with entrance-lock 80 feet to 160 feet by 800 feet; Newport, 72 feet by 503 feet; Avonmouth, 70 feet by 454 feet; Barry, 80 feet and 65 feet by 647 feet; Swansea, 60 feet by 500 feet; Antwerp, 81 feet; Amsterdam Canal, old lock 60 feet by 394 feet, new lock 82 feet by 738 feet; Kaiser Wilhelm Canal, 82 feet by 492 feet; Bombay, 80 feet; Calcutta, 80 feet; Cape, 100 feet.

Dimensions of graving docks are as follows. London, Blackwall, 471 feet long by 65 feet wide by 23 feet deep; Tilbury, 846 feet by 70 feet by 35 feet, and can be divided; Liverpool, New Canada Graving Dock, 925 feet by 94 feet, and 565 feet by 70 feet by 22·4 feet, and 768 feet by 60 feet by 22·1 feet; Birkenhead, 750 feet by 85 feet by 26·7 feet; Belfast, 800 feet by 80 feet by 25·8 feet; Glasgow, 880 feet by 83 feet by 26·6 feet; Southampton, 660 feet by 91 feet by 32·6 feet; Plymouth, 464 feet by 80 feet by 22 feet; Hull, 550 feet by 65 feet by 21·6 feet; Leith, 410 feet by 70 feet

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by 21 feet; Barrow, 500 feet by 60 feet by 22 feet; Newcastle, 550 feet by 80 feet by 26·8 feet; Cardiff, 618 feet by 62 feet by 27 feet; Newport, 520 feet by 65 feet by 32 feet; Barry, two docks, 747 feet by 60 feet by 28 feet divided, and 610 feet by 65 feet by 29 feet in construction; Antwerp, 459 feet by 81 feet by 23 feet; Bordeaux, 540 feet by 72 feet by 27 feet; Dunkirk, 622 feet by 68 feet by 26 feet; Genoa, 622 feet by 68 feet by 26 feet; Bremerhaven, 700 feet by 80 feet by 31 feet; Brooklyn, 595 feet by 85 feet by 25 feet; Sydney, 640 feet by 66 feet by 20 feet, and 608 feet by 84 feet by 32 feet; Buenos Ayres, 587 feet by 65 feet by 26 feet; Chili, 617 feet by 87 feet by 30 feet.

From all these facts—ships, entrances, locks, and graving docks—the Author thinks it may be assumed that, except in the Atlantic trade, there is not a commercial ship 530 feet long or 61 feet broad or with 28 feet draught. The midship cross section of cargo ships has altered completely, and is now nearly rectangular: so that the curved invert of locks and entrances must soon be a thing of the past, and their shape become flat. This will necessitate thickening the side walls. Where the docks themselves are too shallow, pumping in many places is being resorted to, in order to keep the dock level up to high water of spring tides.

It is not an advantage to have a lock of much greater width than the largest ship it has to accommodate; and many locks seem unnecessarily wide compared with their length. A wide dock-entrance with rounded corners is always convenient. It is economical to divide locks and graving docks transversely, so that one portion can accommodate a small vessel, while the whole length can be used for the largest vessel. Room and air-space are of advantage in graving docks; the system of having side bays, and propping vessels only on one side, is the cheapest; and it is better to have a shallow dock for small vessels than to be constantly using a deep one for that class.

Working expenses are more worthy of consideration than original cost, and are too apt to be neglected in designing works. Quick despatch necessitates no waiting for tides; modern docks must if possible have great breadth of quay and shed space, so that each consignment may be dealt with at once; also plenty of trucks, cranes, and sidings. Financial considerations may lead to the transfer of most of our docks to railways, greatly to the benefit of the undertakings, as in the case of Southampton.

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8 JUNE, 1899.

# "Sand-Pump Dredgers."[1]

By ANTHONY GEORGE LYSTER, M. Inst. C.E.

In 1893 the Author read before the International Maritime Congress a description of the operations which had been undertaken up to that time for the improvement of the Mersey Bar by dredging. That Paper dealt so fully with the special features and configuration of the river, and with its tides and winds, that the present note is limited to bringing up to date the information then given, excluding all reference to features which are well known to the majority of the members of this Institution.

At that time, 1893, the operations on the Mersey Bar had been carried on by two small hopper suction-dredgers, extemporised from 500-ton steam hopper barges. A larger dredger, the "Brancker," which was specially constructed for this purpose, and had a carrying capacity of 3,000 tons, and a dredging capacity of about 6,000 tons per hour in the best class of free sand, was just commencing work in July 1893. Since 1895 another dredger of similar construction and capacity, the "G. B. Crow," has been built and employed upon the work; while the two smaller dredgers have been removed to do other dredging abreast of the George's and Prince's stages.

The operations of the two big dredgers have been supplemented by an eroding apparatus, attached to the tender from which the operations were superintended. The function of this apparatus was, by ejecting from a trailing pipe streams of water at high velocity on the ebb tide, to disturb and remove the lighter particles of overlying mud, which tended to interfere with the operations of the big dredgers. This eroding apparatus, after having been worked intermittently for some three years, has now been removed, as it appeared doubtful whether the effect it produced was worth the expense of working it.

For some two years, from November 1896 to December 1898, the operations on the bar were conducted entirely by one dredger; but at the latter date a shoal along the east side of the Crosby Channel, about 4 miles from the mouth of the river, was found to be increasing considerably; and as greater depths were being obtained over the bar than existed at this point of the channel, it was deemed advisable to resume operations with the second dredger upon this shoal.

[1] *The Engineer*, vol. lxxxvii. p. 584; *Engineering*, vol. lxvii. pp. 761 and 789.

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The effect of the operations may be tabulated as follows :—

| | Particulars of Cut through Bar at dates named. | | | Quantity removed from commencement from Bar and Main-Channel Shoals. |
|---|---|---|---|---|
| | Average Depth. | Minimum Depth. | Width of Buoyed Channel. | |
| | Feet. | Feet. | Feet. | Tons. |
| Up to July, 1893 . . . . . | 20½ | 18 | Channel not buoyed | 2,438,710 |
| „ „ 1895 . . . . . | 24½ | 23 | 1,500 | 12,314,120 |
| „ May, 1899 . . . . . | 28 | 27 | 1,500 | 41,240,360 |

Dredging operations are carried out continuously whenever weather permits; and the dredgers when loaded steam to a site about 3 or 4 miles eastward of the bar, and there dump their loads on the weather side of the banks. The only exception to this site for deposit is in connection with the dredging on the shoal on the east side of the Crosby Channel. Here, on the ebb tide and then only, the dredger is permitted to dump her load on the opposite west side of the main channel, in the mouth of a minor channel which was tending to form through the Great Burbo Bank.

The following is the net result of the operations from the point of view of navigation. Whereas at the commencement in 1890 the shallowest water across the bar was 11 feet at low water of spring tides, there is now a channel of 1,500 feet width, having practically no less than 27 feet of water in any part at the same condition of tide. The amount of sand which has had to be removed from the bar itself in order to effect this improvement has been 22½ million tons; and from the bar and main channel together 41¼ million tons, as stated above. As an illustration of what this quantity of material means, it may suffice to say that it would fill up the section of the Thames at Blackfriars Bridge to Trinity high-water level for a length of from 5 to 6 miles.

A comparison between the amount removed, as measured by the capacity of the dredgers, and the deepening of the channel between the buoys, as measured by soundings, shows great variation in the ratio of these two quantities, and in the rate of progress from time to time. But it is obvious that, inasmuch as the soundings were of necessity limited to the dredged channel, they cannot be considered as representative of the actual effect on the whole area affected by the dredging; and any comparison of this sort must therefore of necessity be more or less erroneous. There is no doubt however in the Author's mind that the removal of shoals, and the straighten-

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ing of the channel immediately above the bar, particularly at Q4 Black buoy, have had a great deal of effect in developing and maintaining the improvement obtained by direct dredging on the bar.

As regards the cost of dredging by the large bar dredgers, the year's work of 1898 by the "G. B. Crow" on the bar and in the main-channel shoals may be taken as an example, when 4,309,350 tons of material were removed at the following costs per ton :—

| | d. |
|---|---|
| Wages | 0·23 |
| Supplies | 0·25 |
| Repairs | 0·13 |
| Total | 0·61 |

These figures include all direct working charges, and a proportion of that for actual superintendence, but no allowance for interest on capital cost or for depreciation.

On the question of the improvement of rivers by dredging rather than by permanent works, the Mersey is a striking instance of the permanent improvement which can be effected with a small expenditure by dredging. For instance, the cost of the whole of the dredging plant on the Mersey bar and shoals, namely the two large dredgers, has been say £120,000; and the average annual expenditure for 3 years say £20,000. Had permanent works been adopted, their cost would no doubt have been enormously in excess of the capital cost above mentioned. Moreover there would have been a risk that the depth they were intended to secure permanently might be insufficient for the ultimate requirements which it might become necessary to meet; and therefore that extra expenditure might have to be incurred. The practical results they would have attained could not, to say the least, have well been more satisfactory than those realised by dredging.

As a result of experience in suction-dredging on the bar and elsewhere on the Mersey, an improved form of hopper has been introduced, which obviates the loss of sand and mud that are washed over with the escaping water from the hoppers of the dredgers. On an average it has been found that with an ordinary hopper about 20 per cent. of the sand and mud that are raised is lost through being carried overboard in this way. This material consists not only of light mud, but also largely of sand. Not only is it uselessly raised at the cost of coal, wear and tear, &c., but, as the operations are carried on in positions where the current, in

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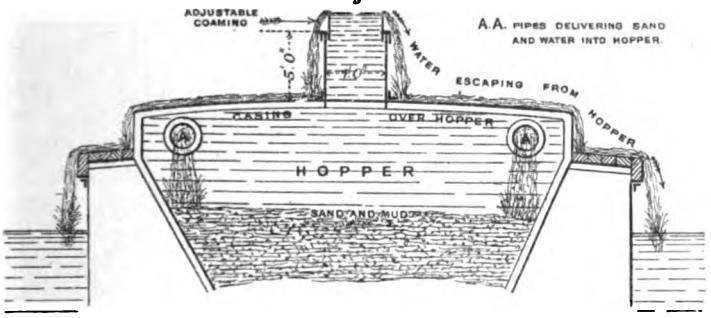
one direction or another, is more or less constant, it is liable to be deposited and form shoals in the neighbourhood of the dredging operations, or to overlay the sand with a fine deposit, which greatly interferes with the efficiency of the suction-dredgers.

To overcome this difficulty, the Author devised the following arrangement (*Fig. 1*). The hopper of one of the smaller dredgers has been covered in with light iron plates, with the exception of a strip along the centre of the hopper 4 feet in width. Here a trunk 5 feet in height by 4 feet in width, and the full length of the hopper, is formed by vertical plates of iron, standing wholly above the covering of the hopper. The upper edges of this trunk are fitted with adjustable coamings, to ensure an even flow over them from the hopper, independently of the trim of the vessel. At the same time, the two delivery-pipes AA into the hopper are laid as close to its outer sides as possible, and the open-

*Fig. 1.*




ings in them are so formed as to ensure the sand and water being delivered with a minimum of commotion. The effect of this arrangement is that all water flowing overboard from the hopper has to traverse a considerable distance in passing from the discharge orifices of the delivery pipes to the upper edge of the trunk over which it flows. The sectional area of the trunk, being 4 feet wide, is such that the rate of vertical motion of the water up through it is reduced to a minimum. The 5 feet head of water which the trunk affords, and the fact that, in the course of its discharge, the water has to rise vertically, have the effect of producing a steady and almost imperceptible flow of the water, which is thus unable to carry with it any sand or silt.

The experiments with this apparatus at the landing-stage show that, as compared with the other dredger which is not so fitted, the water discharged from the trunked hopper is clear in appearance,

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and contains practically hardly any percentage of silt, whilst the dredger is able to load herself on an average in 20 to 25 per cent. less time than her sister vessel which is not so fitted. This is a most important result in view of the output of the dredgers during the year, and the cost per ton of dredging; whilst the addition of the trunk also permits this kind of dredger to be used for lifting very fine sand and mud, for which it has not hitherto been capable of being employed economically.

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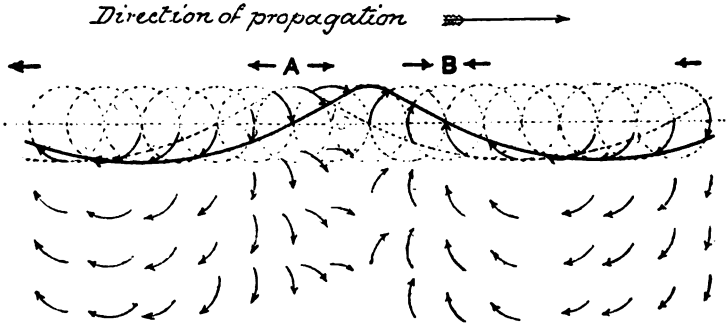
## "Notes on the Effects of Waves on Breakwaters in Different Depths of Water."[1]

By WILLIAM SHIELD, M. Inst. C.E. (Peterhead).

In considering the effect of waves on breakwaters, it may be well in the first place to recall one or two leading points in connection with what is generally accepted as the theory of waves. By so doing it will be possible to compare theory with facts as they are brought to light, and to see how far they are in harmony the one with the other.

The circulation of the water particles in waves of oscillation appears to be approximately that indicated in the following diagram, *Fig. 1*, A and B representing respectively points of departure and arrival :—

*Fig. 1*




[1] *The Engineer*, vol. lxxxvii. p. 584; *Engineering*, vol. lxvii. pp. 761 and 789.

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The movement of the particles is nearly such as would be produced by rolling circles, of diameters equal to the height of the wave from trough to crest; so the form of the wave is approximately cycloidal. When however waves pass into shoaling water, they are affected by bottom friction, and their form is altered, the orbits in which the particles revolve becoming inclined and elliptical. At length the friction of the bottom is such as to cause the crest to overrun the face slope, and the wave breaks. The forward motion of the particles at this time is equal to the velocity of the wave, and the wave-stroke is delivered with its most destructive effect. Waves generally break on entering water of a depth which but little exceeds their height from trough to crest. It may therefore be assumed that the height of waves can never exceed the depth of the water over which they travel. Long ground-swell waves however, although insignificant in height, are often transformed into waves of a dangerous character.

In water having a depth equal to one-tenth of the length of the wave from crest to crest, the relative displacement of the particles is as follows, their greatest horizontal displacement at the bottom being represented by 2·000 :— [1]

| Depth below the Surface. | Horizontal Displacement of Particles. | Vertical Displacement of Particles. | Depth below the Surface. | Horizontal Displacement of Particles. | Vertical Displacement of Particles. |
|---|---|---|---|---|---|
| At surface . . | 2·408 | 1·341 | $\frac{6}{10}$ whole depth . | 2·063 | 0·508 |
| $\frac{1}{10}$ whole depth . | 2·328 | 1·192 | $\frac{7}{10}$ ,, ,, . | 2·036 | 0·379 |
| $\frac{2}{10}$ ,, ,, . | 2·258 | 1·048 | $\frac{8}{10}$ ,, ,, . | 2·016 | 0·252 |
| $\frac{3}{10}$ ,, ,, . | 2·196 | 0·908 | $\frac{9}{10}$ ,, ,, . | 2·004 | 0·126 |
| $\frac{4}{10}$ ,, ,, . | 2·144 | 0·772 | At bottom . . | 2·000 | 0·000 |
| $\frac{5}{10}$ ,, ,, . | 2·100 | 0·639 | | | |

It will therefore be evident that, in all depths of water in which it is possible to construct breakwaters, storm waves will, in a greater or less degree, be waves of translation, while smaller waves may for all practical purposes be considered oscillatory.

The velocity of storm waves which assail breakwaters, inasmuch as their length is always much greater than the depth of water in the immediate vicinity of a breakwater, is proportional (sensibly) to the square root of the depth; it is in fact the same as the velocity which a free body would acquire by falling from rest

[1] "On Tides and Waves," by G. B. Airy, Astronomer Royal, in Encyclopædia Metropolitana, 1848, vol. v. p. 293*, Table IV.

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under the action of gravity, through a height equal to half the depth of the water.

If V = velocity of wave in feet per second,
$g$ = unit of force of gravity = 32·17 feet per second,
S = one-half depth of water in feet,
then in this case $V = \sqrt{2gS} = 8{\cdot}02\sqrt{S}$.

The breakwater which is being constructed by the Admiralty at Peterhead is of the vertical type, and is composed of concrete blocks, weighing about 40 tons each, laid in regular horizontal courses, and joggled and set in Portland cement mortar above low water. Waves up to 10 or 12 feet in height range up and down against its face without breaking or apparently exerting any force beyond the hydraulic pressure due to their height; larger waves however behave in a very different manner. During the storms of December 1896 and January 1897, blocks weighing 40 tons each were displaced in courses bedded respectively at the levels of 17 feet 1½ inch and 23 feet 7½ inches below low water of spring tides. One of these blocks lodged on a concrete platform 30 feet 7 inches below low water, and was washed away during the storm which occurred in the following March.

During the storm of October 1898, which is said to have been as severe as any that has been witnessed in Peterhead Bay, the waves were upwards of 30 feet in height. Blocks weighing upwards of 41 tons each were displaced at the level of 36 feet 7½ inches below low water of spring tides; and a section of the breakwater, down as far as 10 feet 7½ inches below low water, and weighing 3,300 tons, was bodily slued to the extent of 2 inches without the blockwork being dislocated. This enormous mass slid upon the surface of the blocks forming the course immediately below it; and these, strange to say, were not moved. In the waves which were responsible for the slueing of this mass, the water was thrown up to a height of about 115 to 120 feet; and the surface on which they acted measured 33 feet × 34 feet = 1,122 square feet. In order to enable an idea to be formed of the force required to slue such a mass, the Author ascertained the coefficient of friction of blocks similar to those which form the breakwater, by causing them to slide upon a concrete floor. The floor was well wetted, and the average of several trials with blocks up to 68 tons weight gave a coefficient of 0·7. In moving the mass the waves must therefore have exerted a force of 2,310 tons over the whole area exposed to them, or slightly over 2 tons per square foot. Although about one-third of the mass was below the level of

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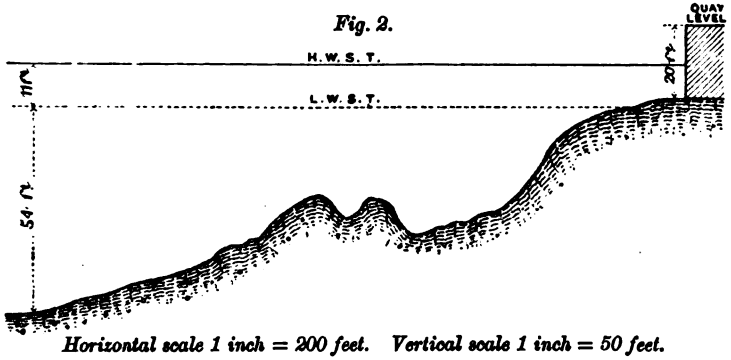
low water, the troughs of the waves would be considerably below its lowest point; and taking all the circumstances into consideration, it is thought that little, if any, allowance should be made for flotation. If allowance however be made for this, it is probable that some deduction should be made from the area exposed to the wave-stroke: so that the above force per square foot would not be much affected.

The depth of water where this happened was about 9 fathoms at low water of spring tides, deepening to 20 fathoms at a mile to seaward. The rise of a spring tide is 11 feet. The length of the waves was about 550 feet to 600 feet, crest to crest, and the depth of water at mean tide 60 feet; the motion of the water particles at a depth of say 36 feet must therefore, according to the foregoing Table, have amounted to 2·063 horizontal and 0·508 vertical, as compared with 2·408 horizontal and 1·341 vertical at

*Fig. 2.*




*Horizontal scale 1 inch = 200 feet. Vertical scale 1 inch = 50 feet.*

the surface. Hence, putting S = 30 feet in the formula, the velocity at the surface would be about 44 feet per second or 30 miles an hour horizontally, and 24½ feet per second vertically; while at the depth of 36 feet it would be nearly 38 feet per second or 26 miles an hour horizontally, and about 9 feet per second vertically.

Fig. 2 represents a vertical quay wall 20 feet high, with a shelving rock fore-shore in front of it; this quay is adjacent to the breakwater at Peterhead. In a photograph taken when ground-swell was breaking against it, the height of the undulations shown would not exceed 4 to 5 feet from trough to crest; and during high tide, with say 7 or 8 feet of water over the rock, such undulations merely rise and fall against the face of the wall, and are reflected without delivering any perceptible stroke. As the tide recedes, however, they are quickly transformed into angry waves of translation, by being tripped up by the fore-shore; and



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they deliver a stroke, the force of which it is difficult to conceive unless witnessed. The broken water represented in the photograph is thrown upwards to a height of more than 100 feet.

The foregoing examples have been cited to show the action of waves against a vertical face; and from them it will be evident that a vertical-faced structure in the sea cannot under all circumstances claim immunity from severe punishment. The comparatively high rubble fore-shores of all such composite breakwaters as those at Alderney, Colombo, and the Tyne, without doubt greatly increase the force of the waves against their superstructures.

The downward action of waves coming against the face of a vertical breakwater often causes serious damage by undermining the foundation. The breakwaters at Alderney and the Tyne are prominent and lamentable examples of this. High parapets, such as both of these breakwaters possessed, greatly intensify this action, and on this, as on other accounts, are objectionable. Mixed rubble, composed of stones weighing from say 5 tons downwards to about ½ cwt., forming an apron on the seaward side of a vertical breakwater, appears to be but little disturbed at a depth of 36 feet by waves 30 feet high; but around the scar-end the scour is very severe, and, unless protection is afforded, the rubble at this point will be washed away, even at depths exceeding 40 feet.

In a composite breakwater with a vertical superstructure founded on a rubble mound, the height to which the mound is carried in relation to the levels of high and low water is of vital importance, and is therefore worthy of careful consideration. Holyhead breakwater is an example in which the mound was carried up to the level of high water of spring tides, and in which the artificial boulder beach thus formed effectually breaks up the waves before they reach the superstructure. The slopes which the mound has now assumed under the action of the waves are approximately 1 in 12 between high and low water; 1 in 5 from low water to 8 feet below it; and thence to the bottom (about 50 feet) 1 in 2.

Alderney breakwater is an example in which the mound was stopped below the level of low water, the rise of tide being 17 feet. The force of the waves assailing the superstructure was thus greatly increased, and the result was disastrous. The slopes assumed by the surface of this mound varied considerably; but at 1,000 feet from shore, where the water was 45 feet deep at low water of spring tides, they were as follows: 1 in 6½ from 3 feet below low water (that being the highest point of the mound) to 17 feet below low water; and thence to the bottom

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1 in 2. In this breakwater the waves not only undermined the superstructure by withdrawing the rubble on which it was founded, but also formed breaches in the wall by their direct impact; while the water falling upon the roadway excavated holes in it, until, the latter meeting those on the sea face, the work was breached completely through. Strange to say, the parapet, in at least one place, spanned the breach and survived the storm. A similar action took place at Wick and at the Tyne.

In the above class of breakwaters, when the mound is not carried up to the level of high water, the addition of a wave-breaker of heavy concrete blocks is often useful, inasmuch as it relieves the face of the superstructure from the force of the wave-stroke, and the waves being in a great measure broken up do not exert so great an excavating action on the rubble as they would do in the absence of such protection. When the Ymuiden breakwaters in Holland were being constructed, and before the blocks forming the wave-breakers were deposited, the rubble which forms the aprons of these piers was frequently ploughed out at a depth of more than 20 feet below low water. The wave-breakers however were effectual in checking this action; and after they had been added, little inconvenience from this cause was experienced. Many of the 20-ton blocks in the wave-breakers were disturbed by the waves, one being lifted to a height of 12 feet vertically up the face of the pier and landed on the top of it. Other 7-ton blocks built into the work were started forward out of their places, by the impact of the waves on open joints compressing the air behind them, which, on the withdrawal of the waves, expanded and pushed the blocks out. On more than one occasion considerable lengths of courses, extending across the full width of the pier, and composed of blocks weighing 5 tons, 7 tons, and 9 tons—all of which were set in Portland cement mortar and tied together by strong wrought-iron cramps—were displaced and washed over into the harbour. The depth of water was 23 feet, the rise of spring tides about 5½ feet, and the height of the pier 4 feet 10 inches above high water.

The subject of wave action on breakwaters in different depths of water presents such a wide field, that it is impossible in a short notice such as this even to touch upon many points of interest and importance. It is hoped, however, that the examples furnished may suggest points for discussion, and elicit useful information, this being the chief object in view. It may perhaps be well to mention here that, among the types of breakwaters with which



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English engineers are least acquainted from actual experience, the several combinations of rubble and random concrete blocks stand out somewhat prominently. Any information respecting the effect of waves on such structures would therefore be highly acceptable. During the winter which has just passed, it is believed that some of the sea-works of this class in the Mediterranean, in common with not a few on British coasts, sustained some damage; and information respecting these would be much appreciated. It would be interesting further to learn in what way the damage was done: whether (*a*) by heavy seas washing over the top, and displacing the uppermost and landward blocks; or (*b*) by the blocks forming the sea-slope being disturbed and drawn down; or (*c*) by the rubble forming the base being ploughed out, either on the sea or harbour side, so that the blocks were undermined.

Other points which suggest themselves for discussion, especially in connection with the effect of waves on breakwaters during construction, are:—(1) sloping versus horizontal bond for blockwork on a yielding foundation; with which, in view of the liability of horizontal courses to slide one on the other, might be associated a consideration of bond between the courses, and also the most effectual method of dealing with settlement in horizontal-coursed work; (2) the best method of checking the travel of rubble in breakwater mounds subjected to oblique wave action; and (3) the best means of avoiding or reducing the destructive effect of wave-stroke on exposed open joints, especially under water, inasmuch as this action takes place at much greater depths below the surface than is generally suspected.

## "The Design of Breakwaters." [1]

By JOHN WATT SANDEMAN, M. Inst. C.E.

(*Abstract.*)

The chief type of modern breakwater, the Author stated, was that of a vertical wall founded either on the sea-bottom or on a rubble mound. Breakwaters consisting chiefly of rubble, or such as had long-pitched slopes of masonry on their seaward side, might be regarded as obsolete. The following data primarily

[1] *The Engineer*, vol. lxxxvii. p. 585; *Engineering*, vol. lxvii. pp. 761 and 790.

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determined the general character, position, and principal proportions of breakwaters:—(1) maximum exposure of the site, and direction of prevailing winds; (2) depth of water; (3) nature and contour of sea-bottom. On each of these heads the chief points which demanded attention were discussed. In considering the question of the dimensions necessary to ensure stability in a vertical breakwater, there was a dearth of definite information. Reference was made to the data recorded by Mr. T. Stevenson and Lieutenant Gaillard with respect to the effect of wave-impact over small areas. It was stated that, in the case of vertical breakwaters which had stood in exposed situations, the majority had a mean breadth somewhat less than their total height. Failures in such breakwaters had always been due to undermining of the foundation. It was not necessary to increase the breadth of a vertical breakwater beyond a certain depth, as it might be assumed that wave-impact ceased at about one-wave depth. Three types of construction might be adopted for vertical breakwaters. (1) For breakwaters upon rock, the most permanent type would be either a monolith of concrete, or a substructure of concrete in bags with a superstructure either of concrete in mass or of large blocks cemented together. (2) For breakwaters upon a rubble mound, a structure of massive blocks of the full breadth of the breakwater, and sloping in the direction of its length, would be the most permanent sort, and Stoney's system of depositing blocks up to 350 tons weight by means of a floating derrick might prove economical. (3) For breakwaters in less exposed situations and in comparatively shallow water, recourse might be had to open timber piling, enclosing a rubble filling. The conditions which must be observed to ensure stability in each of these types were discussed by the Author.

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## Section III.—MACHINERY.

7 June, 1899.

# "Compound Locomotives."[1]

By Francis William Webb, M. Inst. C.E.

For many years the weight and speed of passenger trains had been continually on the increase, with the inevitable result of a demand for more powerful and quicker-running locomotives to haul them. With the object of meeting these requirements, in 1878 the Author turned his attention to the question of applying the compound system to the locomotive, and, as an experiment, converted one of the old engines belonging to the London and North Western Railway into a compound on the Mallet plan, which he worked for about five years on the Ashby and Nuneaton branch. The results were so satisfactory that he was led to give further attention to the subject; and the consequence was that he designed an entirely new mode of applying the compound principle to locomotives, which enabled him, through the arrangement of the cylinders, to dispense with coupling-rods without losing the advantages due to their use. He was also able to increase the size of the axle-bearings and other wearing parts, beyond what was possible in an ordinary locomotive with single frames. In carrying out this plan he used two high-pressure cylinders and one low-pressure cylinder: the former were placed outside the frames, and were arranged to drive the back pair of wheels; and the latter was fixed between the frames, and worked on to the front driving axle. The first engine constructed on this plan was built at Crewe Works in 1881–82, and named "Experiment." The high-pressure cylinders were 11½ inches diameter and 24 inches stroke, and the low-pressure cylinder was 26 inches diameter and 24 inches stroke; the valve-gear used was Joy's. The driving-wheels were 6 feet 6 inches diameter. This engine was put to work on 3rd April 1882; and the results obtained were so satisfactory that twenty-nine more engines of the same kind were afterwards built, but with the high-pressure cylinders increased to 13 inches

[1] *The Engineer*, vol. lxxxvii. p. 565; *Engineering*, vol. lxvii. pp. 737 and 755.

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diameter, while the low-pressure remained 26 inches diameter as before. The total mileage for this class of engine since April 1882 up to 28th February 1899 was 15,093,758 miles, which gives an average of 33,387 miles per engine per annum; the average coal-consumption, including 1·2 lb. for lighting up and all coal used whilst engines were standing under steam at stations, was 34·2 lbs. per mile per engine.

As the requirements of the heavy traffic between Euston and Carlisle demanded still more powerful engines, in 1884 the Author designed and built the "Dreadnought," the first of the class known by that name. In this class the high-pressure cylinders are 14 inches diameter and 24 inches stroke, and the low-pressure cylinder 30 inches diameter and 24 inches stroke. The driving-wheels are 6 feet 3 inches diameter. The boiler-pressure is 175 lbs. per square inch. Forty engines of this class are now running; their total mileage up to 28th February 1899 was 18,681,936 miles, which gives an average of 37,206 miles per engine per annum; the average coal-consumption, including 1·2 lb. for lighting up and all coal used whilst engines were standing, was 39·4 lbs. per mile per engine.

To meet the increasing speed of the trains, in 1889 the Author built the "Teutonic" class. This is in many respects similar to the "Dreadnought" class, the cylinders being the same size; but the driving-wheels were increased to 7 feet 1 inch diameter. In these engines the low-pressure valve-gear was simplified by using a single eccentric, instead of the Joy gear as previously. The arrangement consists of a single loose eccentric on the crank-axle, which is free to turn on the axle into the correct positions for either forward or backward running, as required. The eccentric is connected with the low-pressure valve-spindle by means of a rocking lever, and is driven by a pin projecting from the side of the crank cheek, and engaging with a slotted plate which forms part of the eccentric. The high-pressure valves are worked by Joy gear. Ten engines of this class are running, one of which, the "Jeannie Deans," was shown at the Edinburgh Exhibition in 1890, and since then has been employed in working the 2 P.M. corridor dining-train from Euston to Crewe, returning with the 7.32 P.M. corridor dining-train from Crewe to Euston. The total mileage of this class up to 28th February 1899 was 5,193,126 miles, or an average of 58,241 miles per annum per engine, with an average coal-consumption of 37·9 lbs. per mile per engine; the latter includes 1·2 lb. of coal for lighting up and all coal used whilst engines were standing.

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In 1891 the "Greater Britain" class was built, which the Author specially designed for working the heavy and fast passenger traffic over the west-coast route between Euston and Carlisle. The high-pressure cylinders are 15 inches diameter and 24 inches stroke, and the low-pressure cylinder is 30 inches diameter and 24 inches stroke; the ordinary curved-link motion is used for the high-pressure valves, and a loose eccentric for the low. In this class both pairs of driving-wheels, which are 7 feet 1 inch diameter, are placed in front of the fire-box, in order to obtain a more effective distribution of the weight on the driving-wheels. This arrangement necessitated a long boiler-barrel, which in this case is 18 feet 6 inches long; and the tubes, which are $2\frac{1}{8}$ inches diameter outside, are divided into two lengths by a combustion chamber placed about midway in the length of the barrel. The chamber is fitted with a steam-blast apparatus for cleaning the soot out of the tubes. On 4th November 1891 "Greater Britain" ran her trial trip from Crewe to London with a train of twenty-five empty coaches, at an average speed of $44\frac{1}{2}$ miles per hour. Nine more engines of this class were afterwards built, one of which, the "Queen-Empress," was exhibited at the World's Fair, Chicago, in 1893. The total distance run by this class of engine up to 28th February 1899 was 2,704,537 miles, or an average of 54,454 miles per engine per annum; the average coal-consumption, including 1·2 lb. for lighting up and all coal used whilst standing, was 38·7 lbs. per mile per engine.

As it was thought desirable to increase the number of wagons in goods trains passing over the steeper gradients on some portions of the line, in 1893 the Author designed and built an eight-wheel coupled compound goods engine, with wheels 4 feet 3 inches in diameter. In this engine the cylinders are arranged somewhat differently from those in the other compounds, being placed all three in a line under the smoke-box; the high-pressure cylinders are outside, with their valve-chests inside the frames, and the low-pressure cylinder is within the frames; all drive on to the same axle, the second from the front. The high-pressure crank-pins are set at right angles to each other, and the low-pressure cylinder is connected to a centre crank set at an angle of 135° with the high-pressure crank-pins. Eighty-one of these engines are now running, principally between Crewe and Leeds, Crewe and Carlisle, and Liverpool and Carlisle, and also in the South Wales district; by their use a large number of "banking" and assisting engines have been dispensed with, and the number of trains reduced. The total mileage for these engines up to

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28th February 1899 was 3,628,727 miles, or an average of 28,331 miles per engine per annum; the average coal-consumption, including 1·2 lb. for lighting up and all coal used whilst shunting or standing, was 53·4 lbs. per mile per engine.

In 1894 the Author built the "John Hick" class, which was specially designed for working the heavy passenger trains over the steep inclines on the northern division of the North Western Railway. These engines are in all respects similar to the "Greater Britain" class, except that the driving wheels are only 6 feet 3 inches diameter, instead of 7 feet 1 inch. Ten of these engines have been built, and up to 28th February 1899 have run a total distance of 629,180 miles, or an average of 48,868 miles per engine per annum; their average coal-consumption, including 1·2 lb. for lighting up and all coal used whilst the engines were standing, has been 44·8 lbs. per mile per engine.

The weight of passenger vehicles and the speed of trains being continually on the increase, it became necessary to provide still more powerful engines; and in 1897 the Author designed and built the "Black Prince" class. These, unlike the other compounds previously built, have two high-pressure and two low-pressure cylinders, with a boiler pressure of 200 lbs. per square inch. The high-pressure cylinders are 15 inches diameter, and the low-pressure 20½ inches diameter, both having a stroke of 24 inches. They are all placed in line, and drive on to one axle, which is coupled to the trailing axle behind the fire-box. A feature of these engines is the method devised by the Author for working the valves, so as to require only two sets of valve-gear for working the four valves. The valve-gear used is Joy's, which is applied to the low-pressure cylinders in the usual way. The low-pressure valve-spindles are prolonged through the front of the valve-chests, and each spindle is coupled up to one end of a lever of the first order, which is carried on a pivot securely fixed to the frame; the other end of the lever is connected to the high-pressure valve-spindle. Thus the high-pressure valves are worked from the low-pressure motions, through the intervention of the levers, which are so proportioned as to give the required travel to the high-pressure valves.

In this class the Author has succeeded in obtaining ample bearing surfaces throughout the engine, the driving axle having a central bearing in addition to the usual side bearings. The "Black Prince" ran its first trip on 2nd August 1897; and in the following October it commenced taking on alternate days the up dining-saloon express, which left Crewe at 5.2 P.M., running

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through to Willesden, 152½ miles, without a stop; and returning to Crewe the same night with the Scotch sleeping-saloon express, leaving Euston at 11.50, and running through to Crewe without a stop. Two of these engines are now running, and eighteen more are in course of construction. The total mileage for the two engines since they were first turned out and up to 28th February 1899 was 190,324 miles, or an average of 57,820 miles per engine per annum; the average coal-consumption, including 1·2 lb. for lighting up and all coal used whilst standing, was 40·3 lbs. per mile per engine.

As regards economy of fuel, from careful and exhaustive experiments made by the Author, the saving due to compounding is about from 19 to 20 per cent.; and this is confirmed by observations made in the United States.

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On the invitation of the Author, and by the kindness of the Directors of the London and North Western Railway, an interesting and instructive visit was made by a large number of the Members to Crewe Works on Thursday, the 8th June 1899, by special train drawn by one of the latest four-cylinder compound express passenger engines, the "Iron Duke." The train left Euston at 9.50 A.M., and ran without stop to Crewe, 159 miles, arriving at the works at 1.10 P.M. It consisted of engine and tender, dynamometer car, and thirteen centre-corridor carriages.

*Engine.*—Compound, with four wheels coupled. Cylinders: two high-pressure, 15 inches diameter and 24 inches stroke; two low-pressure, 20½ inches diameter and 24 inches stroke. Wheels: driving and trailing 7 feet 1 inch diameter; radial truck 3 feet 9 inches. Wheel base: centre of radial truck to centre of driving wheels 10 feet 4½ inches; centre of driving wheels to centre of trailing wheels 9 feet 8 inches; total 23 feet 2 inches. Boiler: mean diameter outside plates 4 feet 2⅞ inches; length of barrel 10 feet 11⅞ inches; length of fire-box (outside) 6 feet 10 inches; width of fire-box (outside) 3 feet 11 inches; number of tubes 225; diameter of tubes (outside) 1⅞ inch; boiler pressure 200 lbs. per square inch. Heating surface: tubes 1,220·5, fire-box 159·1, total 1,379·6 square feet. Fire-grate area 20·5 square feet. Weight of engine in working order: on radial truck 18·9 tons, on driving wheels 18 tons, on trailing wheels 17·5 tons; total weight 54·4 tons. Weight of tender in working order 26·6 tons. Total weight of engine and tender in working order 81 tons. Coal con-
[illegible]n journey of 159 miles from Euston to Crewe 3·1 tons =

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43·7 lbs. per mile; obtained from South Wales. Water evaporated on same journey 5,428·5 gallons = 7·8 lbs. per pound of coal.

*Train.*—Number of vehicles 14. Weight of train, exclusive of engine and tender, 329·25 tons; including engine and tender, 410·25 tons; and including passengers, 420·25 tons. Total length of train, including engine and tender, 716 feet. Number of axles in train, including engine and tender, 62. Ratio of weight of engine and tender to weight of train, 1 to 4·18. Maximum pull on drawbar, at starting 4·75 tons, whilst running 5·25 tons. Speed, maximum 71 miles per hour, average 50 miles per hour. Steepest gradient 1 in 70.

An inspection was made of the principal departments of Crewe Works; and also of the Webb and Thompson plan of electrically worked points and signals in operation at Gresty Lane near Crewe. In the return journey the special train left the works at 4.45 P.M., and reached Euston at 7.51½ P.M., having stopped one minute at Willesden Junction. In Plate 8 are shown diagrams giving particulars of the gradients throughout the whole length of the journeys, with the corresponding speed attained and the drawbar pull.

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## "The Relative Advantages of Different Kinds of Power for Tramways, Light Railways, and Motor-Car Traffic, both Heavy and Light."[1]

By THOMAS PARKER, M. Inst. C.E.

(*Abstract.*)

Horse traction upon tramways had many disadvantages besides its costliness. The average cost per mile, with a car weighing 2·75 tons empty and seating 26 passengers, might be taken at 7·78 pence, made up as follows:—driver's and conductor's wages 2·50; horses, forage, renewals, attendance, harness, &c., 4·53; management and general expenses 0·75*d.*

Steam traction, though quicker and less costly in proportion to load, had yet greater disadvantages for street tramways. Practical working had shown that the cost per mile, with a car weighing

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[1] *The Engineer*, vol. lxxxvii. p. 565; *Engineering*, vol. lxvii. pp. 740 and 756; *The Electrical Engineer*, vol. xxiii. p. 723; *The Electrician*, vol. xliii. p. 234; *The Electrical Review*, vol. xliv. pp. 964 and 998.

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12 tons empty and seating 54 passengers, might be taken at 8·99 pence, made up as follows:—driver's and conductor's wages 3·50; locomotive repairs 1·75; car 0·50; fuel 1·65; lighting 0·33; management and general expenses 1·26*d.*

Compressed air had better prospects of success than steam; the proportion of dead load per passenger was in its favour, and it appeared to be more economical than the use of steam direct.

Endless-rope traction had many high merits; but also serious drawbacks, including heavy initial outlay and heavy cost of working. So few tramways were now being laid for rope traction that it might be regarded as having ceased to compete successfully with other plans.

Gas engines working on tramcars were being tried; but no trustworthy practical data were yet to be met with.

Electricity was generally selected at the present time as the best power for tramways. Besides many other advantages, it admitted of great variation in the power exerted at different points on the line. Its disadvantage lay in the conductors being carried overhead; nevertheless overhead wires were at present generally accepted for their attendant practical advantages. Accumulators on the cars had not realised the expectations formed of them; the loss of capacity in the cells during use was a great difficulty. The power required per car-mile with accumulators was about 4·6 E.H.P.-hours; and with overhead conductors about 2·15 E.H.P.-hours, with higher speed and heavier gradients. With overhead conductors the average cost per mile, with a car weighing 4·3 tons empty and seating 30 passengers, might be taken at 3·16 pence, made up as follows:—driver's and conductor's wages 2·49; expenses of generating station 0·46; car 0·04; lighting 0·02; management and general expenses 0·15*d.*

For railways, whether light or heavy, electricity was employed under the most favourable conditions on long runs, and under the least favourable where the stoppages were frequent. For railways on which few trains ran, electricity did not compare with steam locomotives, because the capital outlay for the generating station, dynamos, and conductors, was the same for a few trains as for a number. But for a long run of 50 miles with sufficient traffic, electricity could work trains of 100 tons at intervals of 15 minutes, doing the distance in 40 minutes, at a cost of 2½*d.* per train-mile, and carrying as many passengers as steam trains of 140 tons. On the Liverpool Overhead Railway, which had now been working for nearly seven years, electricity was under its worst conditions in comparison with steam, owing to the number of stoppages

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and the shortness of runs. In this instance the average cost per mile, with a train weighing 31 tons empty and seating 140 passengers, was 4·32 pence, of which 0·42*d.* went for management and general expenses, and the remaining 3·90*d.* for driver's and conductor's wages, expenses of generating station, cars, lighting, &c.

For motor-cars, steam had been early in the field, followed by oil; with both there was still much room for improvement, with prospects of ultimate success in comparison with horses. For electric motor-cars the weight of accumulators had recently been reduced to ½ cwt. per H.P.-hour, or 5 cwts. of cells for a car which two years ago had required 16 cwts. The following data were from one of the best examples the Author had had the opportunity of testing:—weight of car without batteries 9 cwts., weight of batteries 5 cwts., total weight with four passengers 20 cwts.; discharge 12 amperes at 80 volts, giving speed of 9 miles per hour on level; power about 1½ E.H.P.; safe length of run 40 miles; one motor, making 1,200 revolutions per minute, with double-reduction gear.

## "Forgings, and the Machines used in producing them." [1]

By Edward Samuel Brett.

(*Abstract.*)

The basis for accurate forging, it was here represented, was forging by means of dies. In other trades than engineering, work of great utility and beauty, which could be produced by no other means, was cheaply produced in various metals by the aid of dies. While there was much affinity between the pattern-maker and the die-maker, the latter had yet to be appreciated in connection with wrought-iron and steel forgings. As the plastic condition proper for forging could not be retained beyond a limited period, the power employed must be of such a nature as to give an elastic blow of sufficient force to produce an immediate and substantial effect upon the metal. For forgings which should not need finishing afterwards by some other process, the steam hammer was too rigid, and its blow too dead; and the same objection applied to hydraulic power, or to the use of cams or cranks. The accuracy of the work produced by employing ordinary drop hammers and

[1] *The Engineer*, vol. lxxxvii. p. 566; *Engineering*, vol. lxvii. pp 740 and 864.

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friction hammers for forging small articles in dies indicated a right principle; but both these plans involved objectionable features, and were limited in power. Machines were stated to have been recently adopted in the works of the London and North Western and the Great Western Railway, whereby forgings were already being made of moderate dimensions, with prospect of rapid progress in size and finish. In these forging machines none of the parts affected by the work were bolted together or otherwise rigidly fixed; the guides were held, and the dies set in position, with wood packing to absorb vibrations. The lifter was a cylinder with a partly rotating piston worked by steam or compressed air; arms secured to the piston rod were attached to the hammer by ropes or chains or steel bands. The efficiency of the plan was proved; and the lifter could be made to work a gravitation hammer of any weight desired.

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9 JUNE, 1899.

## "Machine Tools: with special reference to American and German practice as compared with English." [1]

By ARTHUR GREENWOOD, M. Inst. C.E.

In introducing this subject for discussion, the writer purposes dividing machine tools into four classes, namely:—

1. Planing machines; with which may be grouped shaping, slotting, and machines used for cutting straight surfaces of metals with knife-edged tools by reciprocating motion.

2. Lathes and boring machines, for cutting circular surfaces of metals with similar knife-edged tools.

3. Milling machines, for cutting straight or curvilinear surfaces of metals with circular rotary saw-like cutters.

4. Automatic machine tools, for special purposes.

*Planing Machines.*—It is upon the planing machine that the engineer relies as the basis in mechanical construction. His first requirement is a true flat surface; secondly, speed in obtaining that result; and thirdly, economy in wear and tear, and facility of maintenance in an efficient state. Strength and rigidity are the

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[1] The *Engineer*, vol. lxxxvii. p. 613; *Engineering*, vol. lxvii. pp. 800 and *Electrical Review*, vol. xliv. p. 965.

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main factors in obtaining these results. It has therefore to be considered what is the best form of bed surface, the best section of cross-slide, and the best driving-gear.

In the earliest planers, acute V surfaces were used, doubtless in order to resist the strain of side-cuts and to take up the wear automatically. These V's, of from 60° to 90°, have been gradually flattened, with beneficial results as regards scoring, until 140° is a common practice; but all V's are difficult to make a good job of in the first instance, and still more difficult to correct when by wear they become hollow or assume a "wind." The latest practice is to use flat surfaces with square or angular lips, and taking-up slips to take the side strains. By this plan a thoroughly good job is much more easily made in the first instance, as bed and table can be scraped to surface-plate independently; and they are much more readily tested and readjusted when in use. The flat bed is gradually being adopted in England, and to a less extent in America and on the Continent; but even here the prejudice in favour of V beds dies hard. In some dozen large planers just completed or under construction by the writer's firm, V's have been specified by the purchasers in most cases, sometimes with a central flat surface; only in two or three cases have the makers been allowed to carry out their recommendation of flat surfaces alone.

The latest practice in cross-slides is the square lip on the upper side, certainly in America, and to some extent in this country, particularly for heavy machines. Many attempts have been made in the past to make planers duplex in their action, either by reversing the tool or by arranging the machine with two sets of uprights and cross-slides, so as to cut in both directions; either method obviously can be used with advantage in plain surface work only, and both of them are seen more in England than in America or Germany. To economize time in running back, the Americans are leading the way by using much quicker return of table, up to and even beyond four times the cutting speed. This necessitates particularly perfect gearing and accurate reversing gear, friction clutches being often used; it absorbs, at any rate momentarily, a large amount of power, as those using electric driving can readily see by watching the ammeter.

For driving gear in this country, the screw is much in favour; it works smoothly and simplifies the gearing, but is not quite so economical in power as well-adjusted rack gearing. The Americans generally prefer rack gearing, and are obtaining splendid results with engine-cut fine-pitched gear. The compromise between the screw and the rack, originated by Sellers in the United States, is

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largely used there, and has been followed by some English and German makers. Unless the gearing is very accurately pitched, there is a material increase in the power used. The most economical planer for general work would appear to be the single-acting machine, with a much higher speed of return, and with a most accurate reversing gear which can be easily adjusted whilst the machine is running, so as to reduce the idle time of the machine to a minimum.

*Lathes.*—In England the upright V, generally in conjunction with a flat, was originally used for lathe beds. Now however flat-surfaced beds with angular edges, or, as they are sometimes called, "gib" beds, are almost invariably used, being generally considered more robust and more readily kept in repair. The Americans however, with one or two notable exceptions, adhere to the upright V, generally double; and this constitutes the leading difference between Eastern and Western lathes. The saddle mounted on the V's moves with less friction; but for heavy cuts this advantage is lost, because the saddle must be weighted or retained by a lip in order to prevent the cutting tool from running in.

As regards headstock and spindle, the parallel neck is more used in the United States than in this country, where conical necks are generally employed for small lathes and parallel necks for the heavier ones. Cones and belts for traverse gear are now being generally discarded in favour of direct gearing, both in England and in the States; and the lathe headstock of the future, having a variable-speeded electric motor combined with it, will soon see the end of belt-driving, at any rate so far as lathes are concerned. In lathes generally, the Germans follow more closely the English than the American style.

Before leaving lathes, notice must be taken of the general adoption, particularly in America, of the horizontal face-lathe or boring mill, which offers facilities both for speed and accuracy. Turret lathes may be grouped with automatic machinery.

*Milling.*—This is one of the earliest known ways of cutting metal, doubtless temporarily eclipsed by the development of planers and other tools under class 1. Both in America and in this country, manufacturers of articles where great repetition occurs—such as rifles, sewing and some textile machinery—have used milling for the past forty or fifty years; and the development of this method of cutting metal, as seen in the modern universal miller in a well-equipped tool-room, leaves little to be desired for rapidity, accuracy, and general adaptability. During the past

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fifteen years milling machines have been largely introduced for heavy work, notably for locomotive and engine builders; and in this direction English tool-makers have certainly been to the fore. Some of the continental makers have carried milling to questionable lengths, particularly in France, where it has been seen in use for work which might have been more advantageously done on planing machines. In England and America, and in France, vertical millers are used principally for plain and curvilinear work. Many are also made on the planing-machine plan, with either horizontal or vertical spindles or both. This is an excellent class of machine, particularly for straight work. The Germans often go to the length of combining this kind of machine with a planer; but as a rule combination machines are to be avoided.

*Automatic Machinery* for special purposes is now coming much to the front, chiefly in America; but both this country and Germany are moving in the same direction. Where great repetition of parts is required, there can be no doubt of its advantage. A general plan of machine is a hollow spindle lathe, with automatic feed and chuck for the material to be operated upon, a saddle with turret rest, back and front transverse slides, all driven automatically from a cam shaft. This machine will produce studs, screws, bolts, and other analogous work from the solid metal bar. By the use of special chucks, one fixing will suffice for finishing wheels, pulleys, cylinder-covers, and other parts of engines or machinery, as against innumerable chuckings in the ordinary boring and turning lathes. The advantages claimed for this plan are that a comparatively unskilled operator may attend to a number of machines, while the tools and tool-adjustments are controlled by a skilled mechanic. The enormous advantage of this mode of manufacture must not be sacrificed by attempting to do too much; and discrimination is required to see that work which can be better done by separate operations is not attempted on this class of tool. In turning work from the bar, such as studs, bolts, &c., care must be taken that the advantage gained by saving of labour is not lost by waste of material; and articles having large differences in diameter may often be advantageously forged, and finished in other kinds of automatic or other lathes. Now that the gearing of nearly all machine tools is engine cut, automatic gear-cutters are largely used; one attendant serves a number of machines.

In machine tools generally, with some recent exceptions, the Germans have followed pretty closely the English lines, but have produced cheaper and lighter tools, and have lacked originality.



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The Americans, on the other hand, have struck out on lines of their own, based on those of some of the earlier English makers. Their machines are generally well made, convenient to manipulate, but of lighter construction, and have not the endurance of the English tools. The English tool-makers for a long time were practically the makers for the world. For strength, stability, and downright wearing capacity, they still hold the first place; the one reproach that may be brought against them is their comparative slowness in producing tools required to meet the growing and changing requirements of the trade, which gives the Americans a certain pre-eminence. Probably one of the reasons is that in this country tool-makers attempt too many varieties. Nearly every maker here produces all the various classes, whilst in America each generally confines himself to one. Whether this is arrived at by mutual arrangement, or is the consequence of their practical nature, the result is satisfactory in the production of machine tools of standard sizes suited to the requirements of the hour, and, by reason of this standardization, at an economical cost.

## "Separate Condensing Plants for Factory Purposes."[1]

By Sir Alfred Seale Haslam.

*(Abstract.)*

It was pointed out that in modern practice it was found advisable, in electric-light stations and other large works employing a number of engines, to have a single large condenser common to the engines of all sizes, instead of providing, as formerly, a separate condenser to each large engine. By this means, in comparison with non-condensing engines, an economy in coal-consumption had been secured, amounting to 20 or 30 per cent. On board ship the plan was of great value, enabling all the auxiliary engines to continue to work condensing when the main engines were not at work; their efficiency and economy were maintained, and their condensed steam was available for feeding the boilers.

Of the four classes of condensers—injection, ejector, submerged or closed surface-condensers, and evaporative or open-air—injection condensers presented the advantage of simpler construction, fewer

[1] *The Engineer*, vol. lxxxvii. p. 615; *Engineering*, vol. lxvii. pp. 802 and 828; *The Electrical Review*, vol. xliv. p. 964.

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working parts, less liability to get out of order, easier cleaning, and lower first cost. Their disadvantages were the necessity for a supply of condensing water that was of good quality, otherwise the boilers could not be fed from the hot well, and the condensed steam would be lost; and they did not produce so good a vacuum as immersed surface-condensers properly constructed. Some were made vertical, and others horizontal; the air-pumps were either single or double-acting, and were fitted either with buckets or with plungers.

Ejector condensers required no air pump. The exhaust steam entering the ejector at a high velocity, and meeting with about twenty times its weight of cold water, produced a jet with momentum sufficient to force its way into a water-sealed discharge pipe or hot well; the condensation and efficient vacuum depended upon the length of the water and steam columns. Here again good condensing water was necessary, and careful adjustment of the ejector, which was apt to be stopped by a little dirt. Generally the vacuum obtained was not higher than from 14 to 18 inches of mercury.

Immersed surface-condensers were more expensive than the two above, and were considered the most efficient; their application to marine engines had been most beneficial. Their advantages were that any kind of condensing water could be used; the boilers were fed with condensed water already at a high temperature, and could therefore be smaller; fuel was saved by less frequent blowing off with cleaner feed; and with less deposit the boilers lasted longer. The disadvantages in comparison with injection condensers were the additional circulating pump for the condensing water, the greater space required, the necessary cleaning of the tubes, the higher first cost, and the larger quantity of condensing water needed on account of the water and steam not coming in contact with each other.

Evaporative or open-air surface-condensers, introduced about half a century ago, had latterly received increasing attention, and were now being made in various forms. Where they had been exposed to the wind, the vacuum on a windy day had been found to be increased; and fans were now used, whereby the efficiency was improved, and the consumption of circulating water was reduced to only about one-thirtieth of that with an immersed surface-condenser. The tubes employed were either cast-iron, wrought-iron, copper, or brass, arranged either vertically or horizontally; the condensing water was distributed over them in various ways, with the object of keeping their whole external



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surface continuously wetted. Wrought-iron tubes, even though galvanized or otherwise protected, did not last long. Copper was more than twice as efficient as iron for condensing. Plain cylindrical tubes were easier to keep clean than those having corrugated or partially flattened surfaces. The main requirements in evaporative surface-condensers were simple form, sufficient surface, and good joints carefully made with special tools. Owing to the number of joints, the vacuum obtained was not generally so good as with an immersed surface-condenser.

## "Cranes, and the Power to be used with them." [1]

By WALTER PITT, M. Inst. C.E.

*(Abstract.)*

Cranes might be roughly divided into two classes:—those carrying their own motive power; and those actuated by power conveyed to them from a separate source. The former comprised hand and steam cranes; the latter included those driven by shafts or ropes, or by electric or hydraulic power. Hand cranes were generally out of place for loads over 10 or 12 tons. Steam cranes were best to use singly, or as portable cranes with extensive travel, being simple to work, as economical as most others, ready at short notice, and requiring little permanent work for ordinary sizes. Overhead travellers were well adapted for driving by shafts or ropes or electricity. Those driven by shafts did well where the motive power was not too far away; but the loss in friction was here a maximum, the speed of the shaft was limited, and the tumbler bearings were apt to be troublesome. Driving by a light quick-running rope had proved a decided advance; the speed was reduced at the crab by worm-gearing.

Electricity had solved satisfactorily all the difficulties previously experienced in transmitting power to cranes. Electric leads were easy to erect, noiseless, motionless, cheap; they conveyed power along routes otherwise impracticable, with considerable economy, and with the still more important advantages of speed and convenience of working. A single motor had at first been

[1] *The Engineer*, vol. lxxxvii. p. 614; *Engineering*, vol. lxvii. pp. 801 and 829; *The Electrical Engineer*, vol. xxiii. p. 724; *The Electrical Review*, vol. xliv. p. 1015.

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employed, often running continuously; and the various motions had been derived from it by shifting belts or by friction clutches. Latterly a separate motor had been used for each motion. Series-wound motors had been substituted for the previous self-governing shunt-wound motors; the series-wound motor with its high starting torque presented a great advantage for single-motor cranes. Jib cranes were now usually made with two motors, one for lifting and one for slueing; by change of gear the latter was used also for derricking and travelling. Speed was reduced from motor to first-motion shaft by worm or cut gear; a worm was noiseless, often highly convenient, and worked with fair efficiency. Liquid resistances had been adopted for controlling gear; or else controllers like those used on tramcars. Though endeavours had been made that the power lost in lowering might be utilized for generating current in the motor, yet, with a view to efficiency of work, quick lowering with a free barrel controlled by a foot-brake might be preferable to economy of current.

Hydraulic cranes would probably continue to be employed, despite the serious rivalry of electric cranes, which, though more expensive themselves, were less costly in generation and transmission of power, were not affected by frost, and were simpler to repair. Overhead shaft-driven travellers, actuated by hydraulic engines from a pressure main, had proved satisfactory. For utilizing a good natural supply of water under moderate pressure, a cheap and efficient hydraulic crane had been constructed by the Author, with a Pelton wheel keyed direct on the pinion shaft of the lifting gear. He recommended steam for single cranes, or for those with extensive travel; and electricity for overhead travellers, or where power had to be conveyed to a distance, or where circumstances warranted a central power station.

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## SECTION IV.—MINING AND METALLURGY.

8 JUNE, 1899.

# "Modern Improvements in Coal-Mining: Winding from Deep Mines."[1]

By HENRY WILLIAM MARTIN, M. Inst. C.E.

There are few more important or difficult problems to be solved, in connection with coal-mining at great depths, than that of winding or raising the coal through the shafts. The capital outlay incurred in sinking and equipping a deep colliery is frequently large, and the necessary working expenses so heavy, that only by raising large outputs can undertakings of the kind be made remunerative. Large outputs from great depths of 700 yards and more with the present modes of winding can be obtained only by raising heavy useful loads at high velocities. Without asserting that the limit has been attained, either of heavy useful loads or of high velocities, it may safely be stated that to increase either or both would also increase in a high ratio the difficulties of winding. With even the lightest appliances, the useful load raised forms but a small portion of the weight which has to be started from rest, accelerated to a high velocity, maintained thereat for a short period, and brought to rest again, during every complete wind or journey through the shaft—an operation which should be accomplished in the shortest possible time.

Engines are constructed, capable of developing much greater power than is required for colliery-winding; but in order to perform the work economically, in the intermittent manner demanded by rapid winding, there is still much room for improvement. The power developed by the engine is expended in raising the useful load, in overcoming the frictional resistances of the winding apparatus, and in communicating velocity to all the moving parts. When the speed is low, the power expended in the last way is small; when high, it is considerable, and should be utilized in assisting to raise the load, and to overcome the frictional resist-

[1] *The Engineer*, vol. lxxxvii. p. 586; *Engineering*, vol. lxvii. pp. 762 and 791; *The Colliery Guardian*, vol. lxxvii. p. 1050.

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ances before the wind is completed; but a large portion is frequently expended in friction on the brake. An important object in the design of winding machinery is to render the demands on the power of the engine as nearly uniform as possible. Many devices are resorted to for attaining this object, and are more or less successful. Two only will be instanced here, both of which are well known, and have long been in use, namely:—

1. The employment of a balance rope.
2. The adoption of a spiral drum of varying radius, generally of a conical form.

Balance ropes have not been extensively adopted for deep winding, and where used have not always been successful, although they are now more or less returning to favour. The objections urged against them are the extra strains on the caps or sockets of the winding ropes, and the increase of friction due to their weight; but the greatest difficulty probably has been found in guiding the balance rope at its return at the bottom of the shaft. Pulleys revolving in sliding bearings and other means have been used for this purpose; but the method considered by the Author the most effective, and the one he adopts, is to use a specially-made flexible and untwisting steel wire-rope, guided sidewise at the return by two vertical parallel plane surfaces only, between which it is allowed to assume a free path.

The radii of spiral drums are often more or less proportioned so that the moments of resistance due to the load shall be constant throughout the wind; and this arrangement is extensively used, with considerable success. It is high however in first cost, and there is an increase of friction due to the extra weight of the drum. There is also a larger mass to be set in motion and brought to rest than with a cylindrical drum and a balance rope.

The following are the main features of the winding machinery adopted by the Author at a new colliery in South Wales, with the view of raising from two shafts a large daily output. The pressure of steam in the boilers is 100 lbs. per square inch; the shafts are each 740 yards deep, and 20 feet diameter in the clear, the depth to coal landing being 700 yards; the useful load is 5 tons; the cages weigh 5 tons each; the pit-head pulleys are 18 feet diameter, and each weighs 5 tons; each tram weighs 12½ cwts. and holds 2½ tons of coal, and at each wind there are two full trams raised tandem fashion, and two empty trams lowered; each cage is guided in the shaft by four steel-wire rope conductors 1¾ inch diameter, weighing 19½ lbs. per yard or 6·65 tons per conductor, loaded at the bottom end with a dead

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weight of 7 tons; two division or rubbing ropes, $2\frac{1}{2}$ inches diameter, hang between the cages to prevent them from colliding when passing each other, and each weighs 29 lbs. per yard or 9·75 tons total, and is weighted at the bottom with a load of 10 tons. Thus far the arrangements of the two shafts are identical.

The winding engine at the south pit has two horizontal cylinders, each 36 inches diameter by 6 feet stroke, and is non-condensing. It has a plain cylindrical drum 17 feet 6 inches diameter, weighing without the shaft 35 tons. Arrangements are being made for fitting it with automatic expansion gear. The winding ropes are untwistable flattened strand $1\frac{3}{4}$ inch diameter, weighing 20 lbs. per yard. A balance rope is attached under the cages, slightly exceeding in length the winding depth of the pit, and of an equal weight per yard to that of the winding ropes.

The winding engine at the north pit has two horizontal cylinders, each 42 inches diameter by 7 feet stroke, and is non-condensing. It has a drum weighing without the shaft 75 tons, one portion of which, for eleven coils, is conical, and the remainder cylindrical; the smaller diameter is 17 feet, and the larger 32 feet, which is also that of the cylindrical portion. The engine is fitted with automatic cut-off gear. The winding ropes are locked coil $1\frac{3}{4}$ inch diameter, weighing 22 lbs. per yard.

At the south pit, at the commencement of the wind, the stress on the rope, due to its own weight, to the weight of cage, trams, and maximum load of coal, and to the acceleration when the velocity is brought up to 50 feet per second in six revolutions of the drum, is 20 tons; and as the breaking strain of the ropes is 180 tons, the factor of safety is 9, which should not be reduced. The ratio of the working stress on the rope to the useful load of 5 tons is 4 to 1; and it is evident that, if the output is to be increased by adding to the useful load, the working stress upon the rope must also be increased in a higher ratio. The output might be increased by more rapid winding, without the necessity of incurring a corresponding increase in the working stress on the rope; but in practice the Author finds that with the machinery described the limit of velocity has been reached. Attempts which were made to increase the speed produced serious oscillation of the cages. Possibly, with a different and more rigid mode of guiding the cages, a higher speed might safely be attained. The shortest time in which a wind has been made in this shaft of 700 yards is 42 seconds; but owing to the oscillation of the cages the speed has been reduced to complete the wind safely and steadily in 50 seconds.

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At the north pit the useful load is also 5 tons, but the working stress on the rope is somewhat greater during the early portion of the wind than at the south pit, partly owing to the use of heavier ropes, and partly to generating the velocity more rapidly; it amounts to 22 tons, or say four and a half times the useful load. The most objectionable feature in this design of winding apparatus is the great weight of the drum. When the whole of the moving parts—comprising drum, ropes, cages, pit-head pulleys, trams, and useful load—have acquired the velocity of 50 feet per second, their kinetic energy is sufficient to complete the last 260 yards of the wind. At the south pit the kinetic energy with the velocity of 50 feet per second is sufficient to complete only 150 yards of the wind. The mean velocity in the latter portion of the wind in both pits is only half of the maximum, and the time required for this portion is therefore double what it would be if the maximum velocity were continued. This portion of the wind is frequently reduced by the application of the brake or by reversing the engines.

At both pits the loading and unloading of the cages on the surface and underground is performed automatically by suitable locking and releasing gear in 8 seconds or less.

## "Modern Practice in Gold-Mining."[1]

By JOHN HAYS HAMMOND.

Problems in metal mining may be classified as those relating to:—(1) Mining Geology; (2) Mining Engineering; (3) Metallurgy; (4) Mechanical Engineering.

(1) *Mining Geology* deals with the determination of the geological character of ore-deposits: having reference specially to their genesis and magnitude, and co-relatively to their commercial values. This is the most important province of the mining engineer, but unfortunately one in which few are proficient.

(2) *Mining Engineering* comprises the problems relating to the methods of opening and working the mine.

(3) *Metallurgy* includes the methods of reducing the ores, and is

[1] *The Engineer*, vol. lxxxvii. p. 586; *Engineering*, vol. lxvii. pp. 763 and 791.

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rapidly becoming specialised. The importance of the problems presented to the metallurgist is obvious, as they relate to the adoption of appropriate processes for extracting the highest percentage of the metals from their ores with the lowest possible reduction charges.

(4) *Mechanical Engineering* comprises the problems pertaining to the erection of mining machinery. To this class likewise belongs the problem of deep mining, of which the salient factors may be pointed out. The great importance of deep mining, that is, of reaching maximum depths, may be gauged by considering the special instance of deep-level gold-mining upon the Witwatersrand. As is well known, this formation is unique in respect of its uniformity, as regards not only the continuity of the ore-bearing formation but also the paying grade of the ore. There are many miles of reef along the Witwatersrand banket-formation; but estimate is here confined to the central, which has been more thoroughly explored than the other sections of the Rand. The value of the gold contents per lineal mile, along the direction of the outcrop of the reef, worked down to a vertical depth of 1,000 feet, has been estimated by the Author to be £9,000,000. The central section embraces upwards of 10 miles, to which the above estimate applies. These figures are obviously sufficient to stimulate the ingenuity of the engineer to increase the limits of deep mining.

The factors determining the limit to which deep mining may be carried are:—(1) depth in itself, that is, cost of deep shafts and of hoisting; (2) ventilation; (3) drainage.

(1) *Depth in itself.*—From an engineering point of view mining could be carried on at depths which would be precluded by considerations of an economic nature. With the existing kinds of winding-engines, wire-ropes, &c., there is no difficulty in hoisting through vertical shafts from depths of 6,000 feet. Improvements in engines and machinery, such as are undoubtedly within the power of engineers, would enable this depth to be considerably increased. From the bottom of the vertical shaft, an incline shaft or a second vertical shaft could be sunk to a vertical depth of say 4,000 feet, giving thus a total depth of 10,000 feet. Such depths increase greatly the first cost of operations, inasmuch as they involve a corresponding increase in the size of the machinery required for shaft-sinking, for winding the mining material, miners, and ore, in addition to increasing the cost of the shaft itself. The actual extra cost per ton of ore &c. raised would not be excessive, and would not greatly militate against profitable

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mining, unless in the shallow levels the margin between profit and loss had already become too narrow.

(2) *Ventilation.*—One of the great obstacles to deep mining is the difficulty of securing the requisite efficiency of ventilation. This is due to the increase of heat in the workings as depth is attained. The heat encountered in mine workings may be due to one or more of the following causes:—(*a*) the increasing secular heat as the interior of the earth is approached; (*b*) proximity of the mine workings to regions of heated volcanic rocks, solfataras hot springs, &c.; (*c*) chemical decomposition of certain constituents of the ores, or of the enclosing wall-rocks, which is confined to deposits of comparatively rare occurrence; (*d*) animal heat, and heat due to the use of illuminants and explosives, all of which are of subordinate importance.

As the result of deep bore-holes and other tests, geologists estimate that the average increment of temperature due to internal heat of the earth is 1° F. for about 60 feet vertical depth. The rate of increase in different localities is by no means uniform; sometimes it is as low as 1° F. in more than 250 feet vertical depth. Even in the same mine the increment of temperature is not invariable, though generally it is fairly constant, and in some mines remarkably so. The isogeotherms are chiefly affected by the proximity of regions of solfataric action or other volcanic phenomena, and by the conductivity of the rocks in which they lie. If 1° in 60 feet be accepted as the average increment of temperature, there will be an increase of 16° per thousand feet vertical, equivalent to 80° at a depth of a mile. Assuming the normal surface temperature to be 60°, this would give a temperature of 140°, which would be by no means insuperable, but at the same time not economical. To counteract the effects of high temperature, artificial ventilation is requisite. Under favourable conditions the cost of the necessary artificial ventilation in metal mines, especially where inflammable and noxious gases are of rare occurrence, would not preclude mining to depths of 10,000 feet. Nevertheless high temperatures, even when not intolerable, entail extra expense, owing to the fact that the miners are thereby more or less incapacitated. Under these conditions short shifts have to be adopted; and not only artificial ventilation, but also the frequent use of iced drinks, cold baths, &c., are necessary.

(3) *Drainage.*—This is one of the least determinable factors. The water pumped from mines is sometimes almost exclusively limited, even in workings of considerable depth, to the upper levels. On the contrary however there is sometimes a progressive

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increase in the water as depth is attained. The increase is by no means constant, and generally varies considerably from level to level, depending upon the character of the ground drained by the underground developments. Where there is an abnormal influx in depth, the expense of pumping becomes a menace to profitable mining, though under normal conditions this increased cost may not prove an insuperable difficulty.

The extra cost of deep mining is thus due chiefly to longer hoisting, and to increased cost of ventilation and of drainage. In the working costs of shallow mines, or of those of moderate depth, these items are small compared with the total cost, in which are included general expenses, costs of development, stoping, metallurgical treatment, &c. Therefore the additional cost of deep mining, entailed by the above factors, could be considerably increased before it would reach a sum which would render deeper mining unprofitable. The factors then, which determine the limit of deep mining, meaning thereby depths of 4,000 feet and more, are:—(1) The discontinuance or impoverishment of the ore-deposit; this, irrespective of other considerations, is the cause of the cessation of deep mining in the majority of instances of abandonment. (2) The excessive costs of original machinery, of ventilation, and of drainage, under unfavourable conditions; this applies especially to the working of ore-deposits where the margin between profit and loss is close. (3) Difficulties of a purely engineering nature. From the foregoing considerations it will be seen that the difficulties included in this last category will not become insuperable until long after the subject of deep mining has become one of academic interest alone.

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## "Notes on Gold-Mining."[1]

By Fearnside Irvine, Assoc. M. Inst. C.E.

In submitting the following notes, which, owing to the limited space at disposal, are necessarily short and somewhat disjointed, the Author has endeavoured to draw attention to the questions which, in his experience of gold-mining in the Transvaal, have seemed to merit most consideration. Of these, in view of the great depths to which the mining industry there is now

[1] *The Engineer*, vol. lxxxvii. p. 586; *Engineering*, vol. lxvii. pp. 763 and 792.

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committed, those bearing on deep-level mining are probably the most important.

*Mine Pumping: Sinking Pumps.*—Pumping from the bottom of the shaft in sinking is seldom resorted to, unless under absolute necessity; the water is generally pumped or baled into the skip, and hoisted to the pumping-station above. When sinking-pumps are used they are suspended in the shaft, and are hoisted up and lowered again at each blast. They are heavy, clumsy, and troublesome, and are best worked by compressed air. A handy and efficient sinking-pump is much wanted.

*Station-Pumps.*—For deep-level pumping, and especially where the shaft is first vertical and then inclined, the Cornish pump is not suitable; it is being rapidly replaced by electrically-driven pumps, either the three-throw vertical-plunger slow-running kind with ordinary valves, or the three-throw vertical fast-running Riedler. Their efficiency for moderate lifts may not be so high as that of the Cornish pump; but, unlike the latter, it does not decrease in depth, and the cost of putting up an electric pump is so much less, that the interest on capital saved more than makes up for any difference, even at first.

*Deep-Level Hoisting.*—The limit of deep-level hoisting not long ago was about 3,000 feet vertical; and at this depth a drum to contain all the round rope necessary without overlaying was neither large nor inconvenient. Now however the requirements of mining demand not only that much greater depths shall be reached, but that the winding speed shall be greatly increased.

The manufacture of high-class wire ropes having rendered it possible to reach the depths required without intermediate winding-stations, the engineer is now called upon to provide a hoisting machine and subsidiary appliances, both above and below ground, which shall enable the fullest advantage to be taken of this advance. Flat ropes, wound on themselves in a reel, are used successfully in vertical shafts; the reels take little lateral space, and the rope is thus easily kept central to the hoisting compartments; but they are bigger in diameter than those required for round rope; while for greater depths the extra weight of the flat rope soon puts it out of court. The wear and tear on flat ropes is much greater than on round rope, and it is inadmissible on inclines. The width of drum required is the great drawback to the use of round ropes for great depths, as it causes the winding rope to make a large angle with the sheave on the headgear. To get over this difficulty, and others pertaining to these large drums, several methods have been devised. In that of Koepe, the rope is simply led round a

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little more than half a turn on a driving pulley, thence over the two headgear sheaves, and down the two compartments of the shaft; a tail rope is used, fastened to the bottom of the skips, so that the whole is worked in balance. Another plan is that of Whiting, which has been tried in the Lake Superior copper mines and on the Rand. It consists of two pulleys or drums, one behind the other; the rope from one compartment of the shaft goes half round both several times, and is then led to a tension-pulley behind the engine-room, round which it passes, and thence over the sheave and down the other compartment of the shaft. Changes of level are easily effected by running the tension-pulley in and out on a track provided for it.

As yet, the steam-engine has full possession of the field as the motive power for heavy winding machinery; but the merits of the electric motor are such, and its claims as an efficient motive power for this class of work are so great, that it should soon begin to displace the steam-engine for winding. The motor can be mounted on the drum-shaft direct, doing away with all the complicated gear of the steam-engine. Each motor would require to be able to hoist the skip when at its lowest level; and the two motors and drums would be coupled by a friction-clutch on the middle of the shaft, all other clutches being done away with. Each motor would act as an electric brake to the other in lowering. With a steam-engine, half its power only is available for starting the load; but in the electric motor the whole power is at once applied. With the electric motors, wear and tear and therefore repairs would be less, and with a proper installation the cost of fuel also.

*Air as Motive Power.*—The transmission of power by compressed air is not nearly so efficient as by electricity, and its employment on a mine should be confined to purposes for which it is absolutely essential; these are rock-drilling, and the working of emergency pumps and of sinking pumps. No electrical drill has as yet succeeded in supplanting the air drill; and no electrical pump is handy enough for the conditions of shaft-sinking, nor indeed would it stand them. Drills have an efficiency of from 35 to 40 per cent. of the power developed by the steam end of the compressor; pumps of from 18 to 22 per cent. Greater efficiency is required in transmission and in utilizing the air in the machines, if this method is to hold its own.

*Ventilation.*—Ventilation of deep mines should be by an exhausting fan in the upcast shaft, supplemented by electrically-driven fans underground, and by the discharge from rock drills.

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*Mine Signalling* requires more attention than is generally paid to it, especially in mines having many working levels, and where sinking is going on at the bottom of the shaft while hoisting is being done from the upper levels. A combination of the electric signalling apparatus employed on ships from the bridge to the engine-room with a separate bell signal, as is now in common use, arranged on two independent circuits with a common return, would seem to answer best.

*Handling the Rock at surface, and sorting* are done by tipping the rock over grids or gratings separating it into three classes: the coarsest is conveyed to the rock-house, and picked or sorted by hand on a revolving sorting table; it then gets a preliminary crushing, is picked again on another table along with the second product, is broken fine, and sent to the mill. The fines are taken to the mill direct from the head-gear. More automatic and labour-saving machinery is wanted in this department.

*Rock-Breaking.*—Breakers are of two kinds, reciprocating and rotary. The rotary crush more rock per horse-power, while the reciprocating cost less for repairs. Improvements are needed in both, but especially in the rotary crusher, in order to bring them up to modern requirements in the way of efficiency and cost of maintenance.

*Hauling Rock to Mill.*—Various methods are used for this purpose, such as inclines with endless rope or chain or tail-rope haulage, more or less automatic elevators and winding drums, supplemented by hand-trucking; but no completely automatic arrangement has been yet introduced, which would be the ideal method of dealing with this problem.

*Milling* a few years ago was one of the most neglected branches of mining work, which has of late years been much improved and gradually brought abreast with the requirements of modern mechanical science. The crushing power of the gravitation-stamp has been raised from 2 tons to 6 tons per head; and a much greater mechanical efficiency has been attained, namely about 92 per cent.

*Treatment of Tailings.*—For elevating the sand and water escaping from the mill, bucket-elevators, centrifugal pumps, plunger-pumps, pulsometers, and elevator-wheels, have all been tried. After passing through many different stages of development, the plunger-pump and the elevator-wheel alone survive. The wheel, being much the most economical in maintenance and efficiency, is used for lifts up to 48 feet; beyond which the pump will probably be best, but will have to be more easily repaired

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and to require less attention than existing makes. In dealing with the tailings, great difficulty was and is experienced in determining the size of launders and classifiers, and in fact with regard to all the hydraulic apparatus, from the want of exact data respecting the carrying power of water. The tailing sands vary greatly in specific gravity, and the grade which gives velocity enough for the tailings of one mine does not do for another; while the additional area required in the launder to compensate for the retarding effect of the sands seems never to have been exactly determined. The method of discharging tailings, which amount to 30,000 tons daily, is another problem awaiting satisfactory solution. It should be as nearly as possible automatic; or at least, after the truck has been hitched on to the hauling rope, it should go out, be tipped, and return empty. This has not yet been successfully effected.

*Treatment of Slimes.*—This part of the product of the mill, after being concentrated from 97 parts water and 3 solid matter up to 60 water and 40 solid matter, is pumped by centrifugal pumps in and out of large settling tanks, in which five or six times its weight of cyanide liquor is first added to it for dissolving the gold; and then, after the gold is dissolved, the cyanide liquor is separated from the solid matter by decantation. It is the difficulty of effectually performing this last operation which constitutes the principal trouble in the treatment of the slimes.

*Precipitation of the Gold from the Cyanide Liquors* is effected by running the gold solution into a tank, in which the metal is precipitated either by the electrolysis set up by the action of the solution on zinc shavings, or by forcing a current of electricity through the solution from an outside source. The zinc method is the cheapest, and has on the whole proved itself the most effectual; but no process has yet satisfied all the conditions of working with cyanide liquors.

## "The Comparative Advantages of Electricity, Steam, and Compressed Air for Mining Purposes." [1]

By Henry Slade Childe, M. Inst. C.E.

The comparative advantages of electricity, steam, and compressed air for mining purposes open out a large field for discussion; but

[1] *The Engineer*, vol. lxxxvii. p. 641; *Engineering*, vol. lxvii. pp. 792 and 805; *The Electrical Engineer*, vol. xxiii. p. 791.

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for the present purpose it may be possible to lay down a few general principles, without merely skimming over such an interesting subject.

*Surface.*—Here in almost every place steam is the most adaptable and economical, and is therefore most commonly used. It can only be in exceptional cases, where it is proposed to carry on some new branch of colliery work, that electricity can successfully compete with steam; and then only when it is not possible to erect boilers, chimney-stacks, &c., or to carry the steam a considerable distance in large pipes, or when it is thought not advisable to have a steam hauling-engine underground in the mine. In the latter event it has been found that by placing the dynamo or generating-plant near the boilers, and by carrying the electric cables in the ordinary course, electricity can be used on the surface, or conducted down the shaft by putting the cables in 1½-inch iron pipes.

*In the Shaft.*—In some instances steam-pumps are fixed in the shafts, below the water-bearing strata, where the water is caught and lifted to the surface. It is seldom possible to use steam for this purpose, except where the pumps happen to be placed in an upcast shaft, which is infrequent. Where they are so placed, the ventilation is of course assisted to some extent by the heated steam-pipes and the exhaust steam; but on the other hand the pump suffers from being fixed in an atmosphere that contains many gases which act injuriously on the different metals.

*Compressed Air* has been tried for this class of work; but, although more advantageous than steam, it does not quite meet the difficulty.

*Electricity* however has been found to answer admirably; and the writer knows of collieries where the pumps are actuated by this power, and are carrying out the work economically and with great satisfaction.

*Underground.*—There are three main purposes for which one or other of these three powers will be required underground: namely hauling, pumping, and coal-cutting.

*Steam for Hauling.*—The steam from the surface-boilers is usually conveyed down the pit in properly lagged pipes, and is then conducted to the bottom of the downcast pit, where the engines are placed. The difficulty of getting rid of the exhaust steam is met by returning it to the upcast, or sending it through into some old return air-ways. Neither of these methods however can be considered satisfactory; there is always some escape of steam from engines and pipes, which is picked up by the air-current and carried into the workings; and for a considerable distance from



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the pit bottom there is moisture, which affects the roof and sides of the mine, and causes them to fall or slip.

*Steam for Pumping.*—The writer knows places where steam has been taken in 6-inch pipes to the distance of a mile from the pit bottom; but in his opinion this was most unsatisfactory, although it did unwater an area of coal that was below the drainage level. The pipes were taken along the return air-way, and, although they were protected, a great amount of steam was lost. The question of getting rid of the exhaust from the steam-pump is not so difficult, because the steam can be turned either into a condenser or into the rising main; but even this necessitates a few minutes' escape of steam every time the pump is started.

*Coal-Cutting.*—Steam is of course entirely out of the question for this work.

*Compressed Air for Hauling* has been found to be most useful when the hauling-engine is placed at the shaft bottom, or in the workings; and the writer is connected with collieries where half-a-dozen hauling-engines are used for bringing coal up inclines and along levels to the main road, whence the main hauling-engine, worked by compressed air, brings thirty or forty tubs to the drawing-pit. The difficulty however of keeping tight joints for compressed-air is considerable; and the loss between the air-compressors and the engine amounts in some instances to as much as 70 per cent., even within the distance of only about three-quarters of a mile.

*Compressed Air for Pumping.*—Whatever may be said of the advantages of compressed air for hauling applies equally to pumping. There are of course a great many places where pumps in mines are worked by compressed air.

*Compressed Air for Coal-Cutting.*—Most of the coal-cutters in use at the present day are actuated by compressed air; and if the main pipes are sufficiently large, and joints can be kept tight, it is a question whether there is any power to beat it. It is easily controlled, and possesses another feature that a mining engineer looks upon as of the utmost value, namely safety, in addition to keeping the working places somewhat fresher and sweeter, and in a manner assisting ventilation; but in respect of economy, it is not, in the writer's opinion, so cheap as electricity. The presence of a line of steam- or air-pipes in any air-way is inconvenient, irrespective of heat and escape of steam; and it must be borne in mind that the roadway of a mine is continually on the move, and that pipes are always leaking more or less, and a good deal of time is required to make a perfectly tight line.

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*Electricity.*—As previously stated this is not used much on the surface. For pumping in shafts it has already been referred to.

*Electric Hauling and Pumping.*—For hauling at the pit bottom electricity is employed at several collieries, and is coming more into use; the ease with which an electric cable can be taken down the shafts and fixed in the roads of the mine is of great value. For small hauling-engines and pumping-engines electricity is most convenient; the motor can be easily fixed and removed, and the great value of electricity lies in the fact that the cables can be taken from place to place with such little trouble. It is difficult to say exactly the difference in time occupied between laying a mile of 6-inch pipes for compressed air and the same length of a cable 1 inch diameter, but it will be about 6 to 1 in favour of the cable; and where hauling and pumping machinery are in main intakes, there is no doubt in the writer's mind that electricity is by far the best agent. He is acquainted with an instance where, in order to work an underground pump in a lower seam, a bore-hole was put down from the upper seam, fully a mile away from the pit bottom, and the cable was passed down through it; this is one example of the adaptability of electricity.

*Electric Coal-Cutting.*—Electricity has been much used for coal-cutting; but it is a moot point whether its many advantages outweigh the risk. Thus far no explosion can be traced to electricity, because its use for this purpose has been comparatively slight; but it stands to reason that, if an explosive admixture comes in contact with an electric spark, an explosion must result. It cannot therefore be used with complete safety, although, if the continuous current is converted into three-phase alternating current, no sparking will occur as there are no rubbing contacts; but even this is not quite satisfactory for complete safety.

*Summary.*—For general surface-work, steam ranks undoubtedly first; for working in shafts and for all underground work electricity has the advantage over compressed air, excepting on the one ground of safety.

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# "The Comparative Advantages of Electricity, Steam and Compressed Air for Mining Purposes." [1]

By WILLIAM EDWARD GARFORTH, M. Inst. C.E.

The use of mechanical power for underground requirements—haulage, coal-cutting, pumping, &c.—is at the present time occupying the attention of mining engineers perhaps more than any other subject.

Whilst high-pressure dry steam is the most economical when generated on the surface in boilers of modern make, and when supplied within a limited distance to the winding and other engines, yet this remark does not apply when the boilers, engines, &c., are placed underground. The expense of maintaining boilers and flues, the danger of setting fire to the surrounding strata, the difficulty of dealing with the exhaust steam, and of obtaining suitable feed-water, &c., render the use of steam unsuitable in the pit. There is also a serious interference with the maintenance of strict discipline amongst the workmen; and since the introduction of the Compensation Act, insurance companies have refused to undertake extra risks without increased premiums. These and other objections will in future prevent the erection of boilers underground.

Many instances can be given of the successful working of underground haulage by engines placed on the surface, and ropes carried down the shaft and for long distances into the workings. Provided local conditions are suitable, and proper attention has been paid to the drums, pulleys of large diameter, ropes and accessories, this method of haulage is probably the most economical that can be adopted, besides giving the additional advantage of safety with respect to inflammable gas in the pit.

To those in charge of coal-mines, which naturally and sometimes suddenly give off large quantities of fire-damp, the fact that compressed air is the safest power implies advantages which compensate to a great extent for the loss of efficiency. The latter can be ascertained; but it is almost impossible to estimate the loss sustained by the stoppage of a large colliery for some months in consequence of an explosion. At the same time, even with the most modern compressed-air machinery—designed on either the wet or the dry principle, single or double-stage compression, water-jacketed, driven by engines and boilers of the most modern

[1] *The Engineer*, vol. lxxxvii. p. 641; *Engineering*, vol. lxvii. pp. 805 and 830; *The Electrical Engineer*, vol. xxiii. p. 790.

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kind, with pipes of large diameter and numerous air-receivers—the losses by heating, leakage, &c., are such that, from an economical point of view, compressed air cannot compare with electricity.

In a coal-mine there are already sufficient natural dangers, from fire-damp and other causes, without introducing artificial risks in addition. For instance, several collieries formerly forced artificial gas from the surface by means of a steam-jet down into the pit, for lighting the roads near the bottom of the shaft and where the traffic was greatest. So long as everything connected with the underground workings appeared satisfactory, no complaint was made; but when an explosion occurred, it was suggested that the cause of the accident was an accumulation of artificial gas above the roadway timbers, due to leakage from the pipes. In the same way electricity is being recommended by some engineers for use at the coal-face in all mines, on account of its greater economy as compared with compressed air. The danger connected therewith may not be fully realised, until an accident takes place, attended with serious loss of life. Then, judging by other accidents, economy is forgotten in regret for the loss of life, and afterwards in consideration of the claims made by the relatives of those who have been killed or injured. There are many mines however in which it will be perfectly safe to use electricity, provided the cables, motors, and accessories combine the latest improvements.

By the use of electricity not only can high efficiency be obtained, but both generating and transmitting machines are exceedingly compact, and require only a limited area; the cables are easily and quickly laid, occupy small space, and being flexible are not affected by the lifting floors of the mine. The cables do not require rigidly fastening underground; it is in fact preferable to suspend them by means of a weak cord from the props supporting the roof, so that in case of a fall of stone the suspending cord breaks readily, allowing the cable to drop, and thus saving it from injury.

With regard to the two systems—polyphase and continuous currents—each has its advantages and drawbacks.

The chief merits of the three-phase current are:—

(1) Absence of commutators in both generators and motors, with consequent saving in wear, reduction of repairs and renewals, and less need of constant skilled attendance.

(2) Complete immunity from sparking.

(3) No starting resistance needed for motors up to 10 B.HP., unless exceptionally large starting torque is required.

(4) Generators of inductor type have all windings fixed. The

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rotor windings of motors have low potential difference, and are not liable to burn out. High pressure can therefore be transmitted, without risk of injury to generator or motor; and copper is saved in the line.

The continuous current presents the following advantages:—

(1) A single pair of conductors is required in place of three conductors.

(2) Greater starting torque can be obtained with the motors.

(3) Accurate measurements can be more readily taken.

From a pitwork point of view, the complete absence of sparking at the motor would at first sight seem a consideration in favour of the three-phase current. The best continuous-current motors for this work however are now usually boxed in, and for all practical purposes are gas-tight. Thus the danger attending the underground use of electric motors is reduced to a minimum. But before adopting electricity, every possible danger should be considered and guarded against, especially in the line of cables. A fall of roof or other accident may at any moment produce a short circuit, or sever the cable and result in serious sparking. Should this take place on the outskirts of an unventilated goaf, consequent on the method of driving straight work and working back the pillars, with a weighting roof and with an atmosphere clouded with fine coal-dust due to the coal-face being cut by a machine, then the production of an electric arc may occasion a serious explosion. The greatest care should consequently be bestowed on this portion of the electrical installation; and the plan which involves the simplest arrangement and least number of cables should be preferred. In the same way that the strength of a chain is only equal to that of its weakest link, so the safety of a mine is only equal to that of the most unsafe lamp or appliance used in it.

With regard to the best form of cable for continuous current in mining work, concentric conductors seem to be the simplest and safest. The adoption of an earthed circuit is open to many objections. Safety is the predominant factor in planning all underground work; and a tight system is on this account to be preferred. Security from shocks is claimed for the earthed plan: but in practice this has not always been found to be substantiated.

For the cable which has to be vertically suspended down the shaft, vulcanized rubber is the best class of dielectric. The very best qualities of rubber, such as are used for high-class underground street-mains, are too soft for this; and a good insulating rubber containing more pigment and of increased thickness should be employed. The core should be lapped with tape and com-

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pounded, and sheathed with galvanized-iron wires of about No. 16 S.W.G. (= 0·065 inch) compounded, and coated with compounded jute. Lead-covered cables should not be used for pit work. All cables should be sheathed.

As a prime source of power, steam, when used under the conditions previously described, possesses the greatest advantages. For the transmission of power to a distance, electricity is the most economical, most efficient, and handiest. In the presence of gas, or with the possibility of encountering it, compressed air is the only power which can be absolutely relied upon for safety. For the distribution of power to distant parts of the mine, the writer has on many occasions advocated the employment of a combination of all three: generating the electricity on the surface by steam power, and conveying it by a cable down the shaft and along the main roads to an electric motor, coupled by gearing or ropes to an air-compressor fixed in a well-ventilated position at a safe distance from the coal-face; then conveying the compressed air through pipes of suitable diameters to pumps, hauling-engines, or coal-cutters, as desired. As the coal-face advances, the motor and compressors are moved forwards. By this arrangement the air-compressing engine-house at surface is saved, and the motor and air-compressor can with a little extra work be fixed in a disused underground road. By a careful consideration of the circumstances and requirements, this combination of the best characteristics of each plan should overcome all objections to the low efficiency of compressed air and to the danger of electricity; and should lead to the realization of an economical and safe method for the distribution of power underground.

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9 JUNE, 1899.

## "By-Product Coke-Ovens." [1]

By EVENCE COPPÉE.

A period of commercial prosperity has now been entered upon, when profits can be made on the manufacture of steel, cast-iron, or coke, however antiquated may be the mode of manufacture employed. Now is the time therefore to provide appliances for the future struggle, which will doubtless result from the excessive increase in means of production.

[1] *The Engineer*, vol. lxxxvii. p. 640; *Engineering*, vol. lxvii. pp. 802 and 829.

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The following figures will give an idea of the increase in production of cast-iron alone in the metallurgical districts supplied with coke by Westphalia, Belgium, and the North of France. It is estimated that the coke-ovens which supply these districts will be 500,000 tons short for 1899, and 1,000,000 tons short for 1900. It is necessary then to meet these demands by new means of production. The manufacture of steel, cast-iron, and coke is also developing in Russia to a gigantic extent. The total number of coke-ovens being built in the South of Russia during this year 1899 may be estimated at 1,500, which will produce an annual increase of 1,200,000 tons; in spite of this, it is estimated that 300,000 tons more coke will be required to satisfy the demand. England and the United States are increasing and improving their means of production to an extent well known by all present. Doubtless this splendid commercial expansion, which corresponds with the extension of the colonial empire of various European Powers and of the United States, while resulting in large profits at present, will lead in the future to competition for the lowest price of production. The cost price of coke will be an important factor in the struggle; and there can be no doubt that in England, as well as on the Continent, the most perfect means of production must be adopted. The most profitable method of production the Author considers is that with coke-ovens in which the latest improvements have been adopted for utilizing the by-products. The estimated shortage of 1,000,000 tons of coke for 1900 in the districts supplied by Westphalia, Belgium, and the North of France, will probably not be fully made up for want of coal; but the increase in production will be almost entirely supplied by ovens in which the by-products are recovered. The superiority of the results obtained is undisputed on the Continent. It is sufficient to know that, during the last two years, great improvements have been made by various builders in the construction of these ovens.

The following results have been obtained in ovens on the Coppée recovery system, which have been recently set to work:—

(1) The coking is perfect, and the quality of the coke is as good as from ovens without recovery.

(2) The production has been increased to 28 or 30 tons of coke per oven per week, according to the kind of coal coked. A charge of 8 tons (metric) of coal is coked in from 32 to 33 hours.

(3) The construction of the recovery oven is as simple and substantial as that of a Coppée oven without recovery. Its life the Author believes will be longer, and the repairs less important,

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owing to the fact that the recovery oven is not subjected to such sudden and frequent variations of temperature as the oven without recovery.

(4) The recovery oven gives at present prices a profit of 2*s.* 6*d.* to 3*s.* 0*d.* per ton on the by-products, according to the richness of the coal and the perfection of the methods of collecting the by-products.

(5) The recovery oven, when using coal containing more than 19 to 20 per cent. of volatile matters, produces also an excess of gas which can be utilized for supplying gas-engines. The quantity of the surplus gas may be estimated at about 3,580 cubic feet per ton of coke produced from coal containing 25 per cent. of volatile matter: or 14,320 cubic feet per oven yielding 4 tons of coke per day of twenty-four hours.

(6) The gases which have been used to heat the by-product ovens pass out of the flues at a temperature of 1,800° F. to 2,200° F. Their heat utilized under steam boilers raises steam enough to supply a 3-HP. engine or thereabouts per ton of coke made.

(7) The oven yields a percentage of coke equal to the theoretical percentage indicated by laboratory experiments.

The cost prices of coke made in the Beehive ovens and in the two kinds of Coppée ovens are compared in the accompanying Table. After crediting the manufacture of the coke with the value of the by-products and the steam and gas produced, the cost price of a ton of coke made upon the three plans, from the same coal at 7*s.* per ton, would therefore be as follows: —

| | |
|---|---|
| Beehive ovens . . . . . | 12*s.* 3*d.* |
| Coppée ovens, *without* recovery of by-products . . . | 10*s.* 6*d.* |
| „ „ *with* „ „ „ | 6*s.* 10*d.* to 6*s.* 2*d.* |

Space is too limited to discuss here the vexed question of the superiority claimed by some metallurgists in this country for coke made in Beehive ovens. Such a superiority may have pertained until now to cokes made with certain qualities of coal rich in volatile matters and also dry; but the Author maintains that it has done so only in these special cases, and that, by adopting the plan of heaping the coal prior to charging it into the horizontal ovens, coke of almost equivalent value to that produced in the Beehive ovens can be made, even with these special kinds of dry coal. As to coke made from really good coking coals, the experience of thirty years upon the Continent and in South Wales

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COST PRICE OF COKE FOR AN OUTPUT OF 840 TONS PER WEEK, WITH COAL CONTAINING 25 PER CENT. VOLATILE MATTER, AND COSTING 7*s.* PER TON DELIVERED AT THE OVENS.

| Per ton of Coke. | Beehive Ovens. | Coppée Ovens without recovery. | Coppée Ovens with recovery. |
|---|---|---|---|
| Yield of ovens . . . . . per cent. | 63 | 72 | 75 |
| | *s. d.* | *s. d.* | *s. d.* |
| Value of coal used for 1 ton of coke . . . . . | 11 3 | 9 8 | 9 4 |
| Labour and repairs . . . . . | 1 0 | 0 10 | 0 10 |
| Total Expense per ton of coke . . . . . | 12 3 | 10 6 | 10 2 |
| *Deduct* profit on by-products—tar, sulphate of ammonia, and oil . . . . . | . | . | 2 6 to 3 0 |
| „ profit on gas, 2.860 to 3,580 cubic feet per ton of coke per 24 hours, corresponding with a saving of 0·16 to 0·20 ton of coal at 7*s.* to produce steam power . . . . . say | . | . | 0 10 to 1 0 |
| Total Deduction per ton of coke . . . . . say | . | . | 3 4 to 4 0 |
| Cost price of coke per ton . . . . . | 12 3 | 10 6 | 6 10 to 6 2 |

shows that this preference for what was done in the good old times is progressively disappearing. After all, one ton of Beehive coke must be worth two tons of coke made in the by-product oven, if the construction of new Beehive ovens is to be justified at the present day.

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## "The Influence of Casting-Temperature upon Steel."[1]

By ROBERT ABBOTT HADFIELD, M. Inst. C.E.

It is difficult to deal briefly with an important question of this nature; therefore the present Paper must be considered as suggestive of the lines upon which research work should be based, and as indicating only in a general way our present knowledge. The question is surrounded with special difficulties, on account

[1] *The Engineer*, vol. lxxxvii. p. 640; *Engineering*, vol. lxvii. pp. 805 and 830; *The Electrical Review*, vol. xliv. p. 965.

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of the fact that the casting-temperature of steel is known only approximately, even with the latest form of pyrometers.

Useful work has been carried out in France with the Noel and Mesuré optical pyrometer; but from various conversations the writer has had with several of the leading French metallurgists regarding the results obtained with this instrument, he thinks that, whilst it is claimed that much has been learned from its use, at the best it gives only approximate results. Seeing that the able American metallurgist, Mr. H. H. Campbell, in his excellent Paper "On the Open-Hearth Process,"[1] states that even a difference of 20° C. to 30° C. causes considerable changes in the behaviour of molten steel during casting, it will be understood how important it is that a thoroughly practical pyrometer, which would enable such differences to be detected, should be perfected. Mr. Campbell's remarks on this subject are so important that it may be well to quote them fully. He states that an addition of 100 lbs. of scrap to a 7-ton bath (100 lbs. in 15,700 lbs.) will cause the temperature to fall about 16° or 20° C., and that this variation is perceptible to the naked eye. An excess or deficit of 500 lbs. in the addition of scrap on the same weight and heat makes the charge either so cold that it skulls badly in the ladle, or so hot that it causes trouble. A variation of 200 lbs. from the true amount, which would show by calculation a variation of about 30° C., is the greatest error allowable in good practice.

Incredible as it may seem, within these narrow limits lies the success of the blower and the melter. Perhaps the best practical pyrometer available, naturally varying according to individual circumstances, is careful observation by the practised eye, in the absence of any absolutely correct data as to the temperature at which steel should be cast. If steel is cast too hot, the ingots or castings are liable to be piped considerably, even though the utmost care be used in pouring; and there are other difficulties, such as segregation. If cast too cold, the metal produced will not work as satisfactorily as it should do during forging, and the ingots will probably be round and unsatisfactory on the exterior.

A peculiar appearance is noted in crucible steel which is cast too hot; it is usually known as "scalded" steel. The crystalline structure is highly pronounced; but by careful re-heating the peculiar appearance noticed seems to disappear, though it is questionable whether the product is even then entirely satisfactory. In a recent correspondence of the writer with Messrs. Huntsman,

[1] American Institution of Mining Engineers, 1895.

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TABLE I.

| 1. Hadfield. | | 2. Pouillet. | | 3. Bowker. | |
|---|---|---|---|---|---|
| Colour. | Temperature. | Colour. | Temperature. | Colour. | Temperature. |
| | °C. | | °C. | | °C. |
| White (not welding heat) | 1,240 | Dazzling white | 1,500 | White | 1,204 |
| High yellow | 1,130 | Bright white | 1,400 | Very bright red | 1,010 |
| Yellow | 1,081 | White | 1,300 | Bright red | 926 |
| Low yellow | 971 | Clear orange | 1,200 | Full red | 804 |
| Bright red | 923 | Deep orange | 1,100 | Red heat | 650 |
| Medium red | 795 | Clear cherry red | 1,000 | | |
| Blood red | 667 | Cherry red | 900 | | |
| | | Incipient cherry red | 800 | | |
| | | Dull red | 700 | | |
| | | Incipient red | 525 | | |

TABLE II.—TEMPERATURES IN DEGREES CENTIGRADE.

| | °C. |
|---|---|
| Melting-point of sulphur | 448 |
| ,, ,, gold | 1,045 |
| ,, ,, palladium | 1,500 |
| ,, ,, platinum | 1,775 |
| ,, ,, white Swedish iron (4 per cent. carbon) | 1,135 |
| ,, ,, gray foundry iron (3½ per cent. C, 1¾ per cent. Si, ½ per cent. P) | 1,220 |
| ,, ,, soft steel (0·10 per cent. C) | 1,475 |
| ,, ,, hard steel (0·30 per cent. C) | 1,455 |
| ,, ,, ,, (0·90 per cent. C) | 1,410 |
| 6-ton converter— | |
| In the ladle | 1,640 |
| In the ingot mould | 1,580 |
| Ingot in re-heating furnace | 1,200 |
| Ingot under steam-hammer | 1,080 |
| Siemens-Martin furnace (steel containing about 0·30 per cent. C)— | |
| End of fusion-period of cast-iron | 1,420 |
| Refining-point of the steel | 1,500 |
| Steel in the ladle (commencement) | 1,580 |
| ,, ,, ,, (end) | 1,490 |
| Temperature of gas from producer | 720 |
| ,, ,, at entrance to regenerator | 400 |
| ,, ,, when leaving regenerator | 1,200 |
| ,, ,, when arriving at chimney stack | 300 |
| Siemens-Martin furnace | 1,600 |
| Rotating puddling-furnace | 1,230 to 1,330 |
| Blast-furnace working on gray Bessemer, near tuyeres | 1,930 |
| Commencement of blast | 1,400 |
| End of blast | 1,570 |

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of Sheffield, who still carry on the manufacture of crucible cast steel, founded in 1740 by the well-known inventor, Benjamin Huntsman, it was stated that, in order to obtain the best quality, scalded steel could never be restored except by re-melting. It will be seen therefore that the greatest possible care should be taken to have the steel prepared during its course of manufacture, in such a way as to obtain the happy medium of temperature, that is, neither too hot nor too cold; but until more perfect pyrometers are produced, this aim can be attained only with constant liability to error.

The temperatures in Table I have been found particularly useful by the writer in everyday work. Column No. 1 represents his own results, obtained by means of a Le Chatelier pyrometer suitably protected in the furnace; this pyrometer is an admirable one, so long as it does not come in contact with molten metal. Column No. 2 represents similar comparative temperatures taken from Pouillet's Tables, and No. 3 from a Table prepared by an American expert, Mr. Bowker.

In Table II are added the melting points of various metals, and temperatures noticed during industrial operations, ascertained by Mr. H. le Chatelier and others, with both electrical and optical pyrometers; these are in some cases necessarily approximate, for the reasons already given.

In conclusion, it will be seen how important a matter is the correct determination of high temperatures; and it is to be hoped that the problem will be followed up, inasmuch as, when once this object has been accomplished, many of the difficulties now met with in preparing and casting steel at the correct temperature will be overcome.

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## SECTION V.—SHIPBUILDING.

7 JUNE, 1899.

# "Swift Passenger Steamers of Moderate Size."[1]

By EDWIN LEWIS MARTIN, M. Inst. C.E.

(*Abstract.*)

Speed and size the Author pointed out were comparative, and in each the tendency was continually to increase. Uniformly high speed at sea in all weathers implied large dimensions. The speed of vessels of moderate size was much influenced by weather; whilst capital, revenue, draught of water and length of voyage limited the size. The problem the designer of swift passenger steamers of moderate size had to solve was, to obtain great power, with the lightest and strongest machinery, in the largest, safest, strongest, most easily-driven and best-formed sea-boat that could be built within the limiting conditions. Speed involved consideration of (*a*) relative engine-power and weight; construction and balancing of engines; class of boiler, weight, space and air-supply; bunkers, coaling and stoking; propellers, single or twin, and their proportions; (*b*) dimensions; and (*c*) form of hull. Safety was paramount and demanded (*a*) strength and durability of hull and machinery; (*b*) surplus buoyancy; (*c*) ample stability; (*d*) water-tight subdivision; and (*e*) life-saving appliances. Comfort required (*a*) all the qualities that go to make an easy and good sea-boat; (*b*) suitable accommodation for passengers and crew, and efficient arrangements for serving; and (*c*) silent and quick appliances for handling mails, baggage and stores. Commercial success being the goal, doubtful expedients must be avoided.

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In illustration of the principles advocated in his remarks, the Author exhibited a model of the two ships "Isis" and "Osiris," recently built by Messrs. Caird and Co., Greenock, for the Mediterranean service of the Peninsular and Oriental Steam Navigation Co., for carrying the mails rapidly between Brindisi and Port Said. Their length between perpendiculars was 300 feet, breadth 37 feet, depth moulded 18½ feet, registered tonnage 1,728, displacement 2,515 tons, load draught 15 feet 10 inches, total coal capacity including reserves 448 tons. The

[1] *The Engineer*, vol. lxxxvii. pp. 566 and 583; *Engineering*, vol. lxvii. pp. 740 and 756; *The Shipping World*, vol. xx. p. 596.

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number of passengers carried was 70 first-class, and the total number of officers and crew 102. There were two sets of four-cylinder triple-expansion engines, each having one high-pressure cylinder 24½ inches diameter, one intermediate 39 inches, and two low-pressure 42 inches, with 36 inches stroke. There were two double-ended and two single-ended boilers, having altogether eighteen furnaces, and fitted with Howden's forced draught. The fire-grate area was 365 square feet, and the heating surface 13,220 square feet. The engines, boilers, and coal occupied 75 per cent. of the total internal capacity of the ship. A speed of 20 knots had been exceeded on several voyages.

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## "On the Practicability of so constructing Merchant Steamers as to render them readily available for War Purposes." [1]

By JOHN HARVARD BILES, M. Inst. C.E.

The two purposes for which merchant steamers may be used by the navy in time of war are: (1) as armed cruisers; (2) as auxiliaries for supplying a fleet with necessaries, and as troop transports. For the former purpose they may have to fight cruisers; for the latter, they will frequently require protection from either armed mercantile cruisers or regular warships, but their ability to do their own duty is undoubted, and need not be discussed.

As armed cruisers, vessels must obviously have considerable speed, and their numbers are in consequence limited. Lloyd's give figures from which the following have been selected :—

| Speed. | Total Number. | British. | | Foreign. | |
|---|---|---|---|---|---|
| | | Above 3,000 Tons. | Below 3,000 Tons. | Above 3,000 Tons. | Below 3,000 Tons. |
| 20 knots and above . . . | 48 | 6 | 21 | 6 | 10 |
| 19 to 20 knots . . . . . | 35 | 1 | 19 | 10 | 5 |
| 18 „ 19 „ . . . . . | 48 | 9 | 30 | 4 | 5 |
| 17 „ 18 „ . . . . . | 83 | 22 | 28 | 18 | 15 |
| 16 „ 17 „ . . . . . | 77 | 17 | 26 | 18 | 16 |
| Totals . . . . | 286 | 55 | 124 | 56 | 51 |

The divisions have been made into above and below 3,000 tons, because the small vessels of high speed do not exceed this tonnage.

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[1] *The Engineer*, vol. lxxxvii. pp. 566 and 584; *Engineering*, vol. lxvii. pp. 741 and 757; *The Shipping World*, vol. xx. p. 596.

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Slower vessels will probably not be used as armed cruisers. The speeds appear to be in most cases trial-trip speeds. Some of the larger vessels have coal-bunker capacity, exclusive of holds, sufficient to enable them to steam at 10 knots speed from 10,000 to 12,000 knots; and if they carry coal in the holds, much greater distances. It may reasonably be assumed that vessels of this character are better able to maintain their speed at sea than war-ships. Their every-day business is to run at some speed called full speed, and most of them do not run at any other speed. It does not follow that they cannot steam easily at lower speeds; but a ship which ordinarily does not steam at full speed is more likely to fall short of maintaining full speed over long periods than one which is in the habit of doing it.[1] In consequence merchant ships have been considered to be most suitably used as scouts or despatch-boats; and no attempt has been made to give them an armament equivalent to warships of anything like their size, power, and speed. Some of the results of arming and fighting the mercantile cruisers of the United States navy seem to point to the ability of these vessels to cope with thoroughbred warships.

One point is deserving of consideration. Is there not a considerable value in a floating structure, whether it is subdivided and protected as a warship, or has no more subdivision or protection than a cargo steamer? It floats, and it offers considerable resistance to sinking, whatever kind of ship it is. Does not the result of modern sea-fighting point to the conclusion that a ship is more likely to be disabled by her crew being driven from their guns, than to be sunk by the effects of shell fire? If this is so, the extra subdivision and protection of buoyancy and stability of a warship over a merchant ship may not be called into play, and the fight between the two will become one of guns versus protection of gunners. This leads to the consideration of the question of portable protection for gunners in the merchant ship.

In the first-class cruisers, casemates are built into the ships. These would be impracticable in a merchant ship. But guns with shields are portable enough, and would place a merchant ship in a highly favourable position compared with a second-class cruiser, as

[1] In the recent Spanish-American war the cruisers St. Louis, St. Paul, New York, and Paris, could steam at 4 knots with the main throttle shut, by the use of the exhaust steam from the auxiliary engines only. About 30 tons of coal per day is the necessary consumption for auxiliary engines; and the exhaust steam was sufficient to propel the ship at 4 knots, and keep the machinery ready for immediate increase of speed to 20 knots. Eight minutes is the time given by the engineers as sufficient to make this change.

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her size and deck area allow her to mount a much larger number of guns. In a Paper[1] read in 1894 before the Institution of Naval Architects, the Author endeavoured to show how large mail-steamers could be made as fit to fight as many first-class cruisers. Portable side armour was proposed, which should be ready for bolting on in time of war. If this system were adopted for the protection of guns, by placing them in a box battery as the Americans have done, and as the Japanese are doing in the ship Mr. Dunn has designed for them at Barrow, a considerable number of guns could be mounted, which could be as well protected as in first-class cruisers. This subject however is too much one of detail to be discussed here; but it is not an impracticable operation to have portable armour put on a mail-steamer.

The work done by the American line steamers in the recent war included scouting, drawing the fire of forts to discover their strength, cable cutting, and carrying troops, coal, and water. All this work can be done by any vessels of high speed and large coal endurance; but it is worth discussing whether, having employed vessels valued at £100,000 to £500,000 each to do this work, it is not desirable to go a little further and make them able to do more, by arming and protecting them so that they can meet second-class cruisers with the chances in their favour, and with a fair chance of holding their own against a first-class cruiser. If they can be made capable of doing this, then the number of cruisers which will be available to protect our commercial routes may be much increased; and we shall not be taking up merchant ships merely because their speed will enable them successfully to run away from the cruisers of an enemy who are destroying their slower sisters, but because they can successfully fight these cruisers. The practicability of designing merchant steamers so as to be readily adapted for war purposes has been discussed in the Institution of Naval Architects. The desirability is always a subject for discussion.

The experience of recent wars points to the desirability of having vessels which can carry large coal and stores cargoes, and which have facilities for readily transferring these cargoes to warships at sea. This work could be well done by some of the large freight carriers of lines which carry mails. Special appliances would have to be fitted to these vessels, which might or might not be carried in the vessels' regular work. In the construction of these

[1] "The Design of Mail Steamers, with special reference to their use for war purposes," by Professor J. H. Biles. Inst. Nav. Arch. 1894–5, vol. xxxvi. p. 45.



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vessels special consideration might be given to their use for such purposes. Some large freight carriers have ocean speeds of 15 knots, and such vessels would be of great service in time of war.

A question arises in connection with the special and ordinary builds of merchant vessels, as to their strength to carry guns. These vessels are generally constructed of scantlings much thicker than those of warships, and many places in their decks are amply strong enough to carry guns. Possibly some parts would require special strengthening, but this could be readily applied if necessary.

In the matter of position of machinery in relation to the water-line, the later vessels of moderate and large size have their machinery and boilers not much, if at all, above the water-line. With a little consideration in the early stages of design and construction, it is easy to arrange the structure so that the coal which these vessels carry will give protection. Twin-screw engines and increased revolutions are tending to make merchant ships more safe in this respect.

The principal point to note, in connection with merchant ships for war purposes, is that a ship of any kind offers considerable resistance to the destruction of its buoyancy and stability: and in consequence, with guns and gunners sufficient and sufficiently protected, the merchant ship need not be much, if at all, inferior to many warships, if special attention be given to the subject in the design of the ship.

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## "Recent Developments in Cargo-Steamers."[1]

By Edwin William De Rusett, M. Inst. C.E.

The Author proposes to confine his remarks to British steamers, and to make his notes general rather than exhaustive in character. They will therefore be confined to the following:—(1) type; (2) size; (3) construction; (4) capacity; (5) cargo appliances; (6) ballasting; (7) economy of working.

No. 1. *Type.*—Among the varieties introduced within the last seven or eight years may be mentioned the "shelter-deck" and

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[1] *The Engineer*, vol. lxxxvii. p. 641; *Engineering*, vol. lxvii. pp. 805 and 831.

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"turret" types. The former has been evolved out of vessels having a poop, bridge, and forecastle, the intervening spaces being gradually shortened, as in the "Westmeath" in 1894; until in the "Milwaukee," two years later, these erections were united by a complete deck with closed-in sides, thus providing a covered-in space, whereby seaworthiness, comfort, and strength have been increased, and greater buoyancy has been secured. The primary object of this type is to obtain large measurement capacity, and to provide suitable habitation for large numbers of cattle and horses. Such vessels are specially suitable for Atlantic service, whereas the type from which this has been developed is still the best adapted for Eastern traffic. Although in this type the dead weight suffers somewhat, it has, in the later vessels, been increased by the addition of two or more bulkheads within the shelter-deck, whereby a diminution of free-board has been obtained. Vessels of from 6,000 to 12,000 tons dead weight have been recently built of this type with excellent results, combining as they do safety and comfort at sea with increased earning power.

As a cargo carrier, the "turret" type of steamer, introduced in 1892 by Messrs. W. Doxford & Sons, is unique in its design; but although it has other advantages, it has not the same relative internal capacity as the shelter-deck vessel. Another departure from the usual type of steamer was introduced in 1896 in the "trunk" variety. All these were probably the outcome of the American whale-backs, which have done such good service in the large lakes.

Vessels specially constructed for carrying oil in bulk have also advanced in size and usefulness, and are now adapted for carrying general cargoes as well as oil, to suit the exigencies of trade. The addition of an awning deck to this type of steamer has rendered such a combination fairly feasible; although of course a tanker could never compete with a pure cargo boat, on account of its increased first cost, and of the large amount of broken stowage caused by the peculiar construction and design necessary for carrying oil efficiently. Most recently a still further advance has been made by the use of oil fuel in such vessels, since oil having so high a flash-point as 200° F. is safe and suitable for liquid fuel. This fuel is carried sometimes in the fore and after peaks, and sometimes in portions of the double bottom, from which it is pumped into the supply tank by special appliances.

No. 2. *Size.*—The size of vessels has rapidly increased of late, as may be observed from the following statement, which has been kindly furnished by Lloyd's Registry:—



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NUMBERS OF STEAMERS (EXCLUDING WAR-VESSELS) UNDER CONSTRUCTION IN THE UNITED KINGDOM ON 31ST MARCH, 1895, 1896, 1897, 1898, AND 1899, BETWEEN CERTAIN LIMITS OF GROSS TONNAGE.

| Gross Tonnage. | Steamers under Construction in United Kingdom on 31st March. | | | | |
|---|---|---|---|---|---|
| | 1895 | 1896 | 1897 | 1898 | 1899 |
| 1,000–1,999 . | 42 | 43 | 49 | 65 | 60 |
| 2,000–2,999 . | 43 | 49 | 54 | 68 | 40 |
| 3,000–3,999 . | 48 | 61 | 63 | 102 | 101 |
| 4,000–4,999 . | 29 | 21 | 15 | 25 | 34 |
| 5,000–5,999 . | 10 | 22 | 19 | 23 | 34 |
| 6,000–6,999 . | 4 | 5 | 11 | 14 | 20 |
| 7,000–7,999 . | 2 | 3 | 4 | 14 | 12 |
| 8,000–8,999 . | 3 | 3 | 4 | 3 | 1 |
| 9,000–9,999 . | .. | .. | 1 | .. | 6 |
| 10,000 and above | 1 | 1 | 3 | 4 | 15 |

The above includes passenger steamers.

It is to be regretted that the cargo vessels are not separated from the passenger steamers in this statement; but it is of value as showing at a glance the remarkable development of merchant vessels generally, including both cargo and passenger steamers.

During all the ages in which mercantile shipping has flourished, there was not any noticeable growth in the dimensions and tonnage of vessels until after the first half of the present century, owing doubtless principally to the fact that wood was the material of which they were built; but in this age of steel, and notably since 1890, the building has risen and has been rapidly developed of combined cargo and passenger vessels of the dimensions originally applied to high-class passenger steamers. So much has this been the case, that, whereas about ten years ago a cargo steamer of 300 feet was considered of fairly large size, and 400 feet exceptionally large, such vessels are now found to have reached nearly 600 feet in length, and between 12,000 and 13,000 tons dead weight, and there appears to be no reasonable limit to their extension, so far as the shipbuilder is concerned; but probably the limits of draught of water on the American side will be a determining factor in the problem.

The following Tables will serve to illustrate this part of the subject. They are compiled from Lloyd's Register, and from the records of W. Doxford & Sons, and C. S. Swan & Hunter; they show the largest vessels of this class built during the last nine or ten years. As a further illustration, reference may be made to the

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development of the turret type of steamer, represented in 1892 by the "Turret," a vessel of 3,360 tons dead weight, and in the present year by the "Clan Colquhoun," a vessel of 8,400 tons dead weight; the increase in dimensions and tonnage has progressed step by step as indicated in the Table.

LIST OF SOME OF THE LARGEST CARGO VESSELS BUILT EACH YEAR ON THE CLYDE SINCE 1890; COMPILED FROM LLOYD'S REGISTER.

| Year. | Name. | Built by | Registered Dimensions. | Tonnage. | | Water Ballast. | Screw. |
|---|---|---|---|---|---|---|---|
| | | | | Gross. | Net. | | |
| | | | Feet. Feet. Feet. | | | Tons. | |
| 1890 | Jelunga | W. Denny and Brothers | 410·5×48·2×30·5 | 5,196 | 3,364 | .. | Single |
| 1891 | Dilwara | A. and J. Inglis | 425·4×48·2×30·6 | 5,441 | 3,517 | .. | ,, |
| 1892 | Agapanthus | A. Stephen and Sons | 380·0×46·0×27·5 | 4,409 | 2,866 | 1,415 | ,, |
| 1893 | Southwark | W. Denny and Brothers | 480·0×57·2×37·0 | 8,607 | 5,642 | 1,255 | Twin |
| 1894 | Kensington | J. and G. Thomson | 480·0×57·2×37·0 | 8,669 | 5,645 | 1,456 | ,, |
| 1895 | Carinthia | London and Glasgow S. B. and E. Co. | 445·0×49·0×31·9 | 5,598 | 3,623 | 831 | ,, |
| 1896 | Glaucus | Scott and Co. | 423·2×49·2×28·3 | 5,573 | 3,591 | .. | Single |
| 1897 | Knight Errant | C. Connell and Co. | 470·0×57·2×31·9 | 7,464 | 4,747 | 3,304 | ,, |
| 1898 | Bengalia | A. Stephen and Sons | 485·0×57·0×32·9 | 7,690 | 4,949 | 2,470 | ,, |
| 1899 | Maplemore | C. Connell and Co. | 459·0×52·5×31·0 | 7,717 | 5,014 | 2,704 | ,, |
| 1899 | Saxonia (building) | J. and G. Thomson | 580·0×64·3×41·6 | About 13,900 | About 8,900 | About 4,500 | Twin |

LIST OF SOME OF THE LARGEST CARGO VESSELS BUILT EACH YEAR BY HARLAND & WOLFF SINCE 1889; COMPILED FROM LLOYD'S REGISTER.

| Year. | Name. | Screw. | Registered Dimensions. | Tonnage. | |
|---|---|---|---|---|---|
| | | | | Gross. | Net. |
| | | | Feet. Feet. Feet. | | |
| 1889 | Ameer | Single | 400·6×45·2×28·1 | 4,109 | 2,682 |
| 1890 | Georgian | ,, | 442·6×45·2×31·0 | 5,088 | 3,318 |
| 1891 | Montezuma | Twin | 430·0×47·0×22·4 | 6,357 | 4,863 |
| 1892 | Bovic | ,, | 470·0×53·1×23·9 | 6,583 | 4,230 |
| 1893 | Cevic | ,, | 500·0×60·0×38·0 | 8,301 | 5,403 |
| 1895 | Georgic | ,, | 558·7×60·3×36·0 | 10,077 | 6,570 |
| 1896 | Pennsylvania | ,, | 560·0×62·0×41·0 | 12,891 | 7,861 |
| 1897 | Cymric | ,, | 585·5×64·3×37·9 | 12,552 | 8,123 |
| 1899 | Afric | ,, | 550·0×63·0×44·0 | 11,850 | .. |

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PARTICULARS OF THE LARGEST "TURRET" STEAMERS BUILT EACH YEAR BY W. DOXFORD AND SONS, SUNDERLAND, SINCE 1892; ALL SINGLE-SCREW.

| Year. | Name. | Dimensions. | Tonnage. | | Water Ballast. |
|---|---|---|---|---|---|
| | | | Gross. | Net. | |
| | | Ft. Ft. Ins. Ft. Ins. | | | Tons. |
| 1892 | Turret | 280×38 0 ×22 9 | 1,970 | 1,274 | 749 |
| 1893 | Turret Age | 311×38 2½×24 1 | 2,232 | 1,383 | 778 |
| 1894 | Royalist | 340×45 6 ×26 0 | 3,188 | 2,025 | 883 |
| 1895 | Oak Branch | 340×45 6 ×26 9 | 3,258 | 2,064 | 855 |
| 1896 | Selma | 340×45 6 ×27 3 | 3,480 | 2,233 | 797 |
| 1897 | Clan Macdonald | 400×50 2½×30 6 | 4,839 | 3,112 | 1,972 |
| 1898 | Noranmore | 420×50 2½×32 6 | 5,649 | 3,677 | 2,315 |
| 1899 | Clan Colquhoun | 440×51 6 ×32 0 | 5,856 | 3,760 | 2,934 |

PARTICULARS OF SOME OF THE LARGEST CARGO STEAMERS BUILT EACH YEAR BY C. S. SWAN AND HUNTER, WALLSEND, SINCE 1891.

| Year. | Name. | Dimensions. | Tonnage. | | Water Ballast. | Screw. |
|---|---|---|---|---|---|---|
| | | | Gross. | Net. | | |
| | | Ft. Ft. Ins. Ft. Ins. | | | Tons. | |
| 1891 | Chancellor | 400×47 0×31 6 | 4,753 | 3,147 | 831 | Single |
| 1892 | Tokomaru | 425×53 0×34 0 | 6,237 | 4,071 | 1,310 | ,, |
| 1894 | Aotea | 430×49 0×32 10 | 5,652 | 3,702 | 1,073 | ,, |
| 1895 | Westmeath | 450×56 0×34 6 | 6,850 | 4,485 | 1,555 | ,, |
| 1896 | Milwaukee | 470×56 0×34 10 | 7,317 | 4,755 | 2,555 | ,, |
| 1897 | Monarch | 470×56 0×34 10 | 7,295 | 4,770 | 2,592 | ,, |
| 1898 | Ultonia | 500×57 4×37 0 | 8,056 | 5,211 | 2,659 | Twin |
| 1899 | Ivernia (building) | 580×64 6×41 6 | about 13,900 | about 8,900 | 4,550 | ,, |

No. 3. *Construction.*—Many modifications have of late years been made in construction. First and foremost is the substitution of mild steel for iron. At the present time it is the exception for iron to be used in any part of a ship's construction, and substantially the whole of the vessels now building are of mild steel. The almost exclusive use of this high-class material has in the aggregate added enormously to the dead-weight carrying-power of the modern cargo vessel. There has been an increasing tendency of late years to avoid waste in the use of material in steel shipbuilding. Some of the more notable improvements that have been effected during the last ten years are:—the overlapping and scarfing of shell-plate butts; joggling at the landing stages of shell plating, decks, inner bottoms, and the plating of transverse watertight bulkheads; also the flanging of internal work wherever practicable. Girder frames have been generally

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adopted in lieu of web and ordinary frames, being a simpler and more homogeneous form of construction. Hold beams have been dispensed with as far as possible, in order to give unbroken spaces for stowing large pieces of machinery, boilers, locomotives, tramcars, railway carriages, bridge work, &c.; and, in order further to facilitate stowage, large wide-spaced hollow columns, pitched about 20 feet or even 35 feet centre to centre, have been adopted in lieu of solid pillars on alternate frames.

No. 4. *Capacity.*—As a matter of course, measurement and dead-weight capacity have increased with the increase in dimensions, especially owing to the fact that, while it has grown in length, the cargo boat has also developed in fulness, experience having proved that larger vessels of corresponding speed may be made fuller without impairing their efficiency. Vessels are now being built having a capacity for about 25,000 tons of cargo at 40 cubic feet per ton, and a dead weight of about 12,200 tons: whereas even as late as 1891 a steamer having a capacity for cargo of 8,750 tons, and a dead weight of 6,750 tons, was considered to be a large vessel. One of the objects every naval architect has before him in designing cargo vessels is of course to obtain large measurement and dead-weight capacity, with a small net register. This object will generally explain the reason for the variety of types of steamers and peculiarities of design. The present-day large steamers are frequently fitted with pens to carry 700 to 800 head of cattle. Vessels have also been constructed with insulated holds sufficiently large to stow 80,000 to 100,000 frozen sheep. The following list of the cargo discharged by the "Milwaukee" in London in September 1897 will give an idea of the enormous and varied cargoes carried by a modern steamer:—

CARGO DISCHARGED IN LONDON, SEPTEMBER 1897, FROM THE S.S. "MILWAUKEE," BUILT BY C. S. SWAN AND HUNTER.

Dimensions of ship 470 × 56 feet × 34 feet 9¾ inches, with complete shelter deck.

| | |
|---|---|
| 514 head of cattle. | 200 bags of starch. |
| 132 horses. | 189,200 bushels of corn. |
| 640 sheep. | 20,025 boxes of cheese. |
| 18,412 bushels of oats. | 399 cases of apples. |
| 1,209 bales of hay. | 11 cases of machinery. |
| 13,149 sacks of flour. | 16,737 deal ends. |
| 51,629 pieces of deal. | 5,723 pieces of birch plank. |
| 16,328 boards. | 134 radiators. |
| 4,398 pieces of lumber. | 880 pails of lard. |
| 195 tierces of lard. | 5,730 bags of grape sugar. |

This is said to be the largest cargo discharged in London up to September 1897. In this condition the ship had 11,100 tons dead weight. It is reported she was discharged in 66 hours actual working time.

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No. 5. *Cargo Appliances.*—This is an item deserving the fullest consideration, and the Author specially hopes that information upon this point will be given during the discussion. It is evident that unless a large vessel has a ready means of loading or discharging her cargo, she will be placed at a serious disadvantage when compared with smaller vessels having a quicker dispatch; also that detention in port neutralizes the advantages gained by speed at sea. Consequently cargo appliances have received a great deal of attention. Winches are made larger than formerly, and are frequently worked with steam of main-boiler pressure. The diameters of barrels and winch ends have been increased for quick working. Chain runners are giving way to light flexible wire-ropes. A great increase has been made in the number and length of derricks; one derrick to each winch used to be the practice; now as many as two are sometimes fitted, with the addition of cargo spans between the masts; and in one instance known to the Author 32 derricks and 10 winches were fitted to a steamer carrying 14,000 tons of measurement cargo. Derricks are also carried to lift 15 to 20 tons. Plenty of steam is a necessity. The number of hatches has been increased; nine are now provided in the largest class of steamers. The length of the largest has reached about 40 feet; but 26 to 30 feet by 16 feet is usually found sufficient. The following may be quoted as an instance of rapid discharge under ordinary working conditions:—the "Monarch" arrived in Liverpool on the 1st October and left on the 9th, discharging a full cargo of 18,500 measurement tons, besides taking in about 1,700 tons of coal; this vessel has nine hatchways, and is fitted with twelve winches and eighteen derricks. It appears to the Author that the only limit to rapid dispatch is the capacity of the sheds, and the facility with which cargo can be gathered or sorted and distributed.

No. 6. *Ballasting.*—As vessels now so commonly leave the ports of the United Kingdom in ballast and bunkers only, it has been found necessary to increase the proportion of water-ballast in order to give sufficient immersion for steaming. Consequently deep tanks have again been resorted to. These tanks are small properly ventilated holds, available for cargo, or alternatively for water-ballast. The largest class of vessels frequently have two of these, besides the double bottom and peaks. A common proportion of water-ballast used to be about one-tenth of the load displacement; it has now reached from one-sixth to one-fourth. With deep tanks however it is advisable to give attention to their arrangement, with the object of reducing the stresses at sea when in ballast trim.

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No. 7. *Economy of Working.*—The ease with which these large vessels are propelled, and the speed obtained with full models, is remarkable. Experience has proved that, in order to produce an economically driven and steady cargo boat, a good deal depends on the harmony of the lines, the proportion of bodies, and the adjustment of power to the average speed required. These features have received more attention of late, since competition has grown keener with the increase in tonnage. As an instance, the "Monarch" may again be cited. This vessel has a block coefficient of 0·810, and a dead weight of about 11,600 tons. During two of her recent voyages to Montreal and New Orleans—each outwards in ballast and bunkers, and home fully laden—she steamed 11·35 knots on the average, with a consumption of 48·3 tons per day. Other large vessels built by Messrs. C. S. Swan & Hunter have shown similar performances.

On account of lightness of draught and other considerations, twin screws are becoming more common: a wise step, inasmuch as shafts have been giving a good deal of trouble lately, and great loss of time and money has resulted. Twin-screw propulsion however has the drawbacks of increasing the cost and reducing the cargo capacity, while the speed is probably somewhat diminished with the same indicated power.

Nothing is spared to make a first-class cargo-vessel efficient in every respect. For safety, shafting of the highest character and the most efficient steering-gears are provided; and for economy, bronze propellers, high-pressure steam, forced and induced draughts have been resorted to. The accommodation for officers and crew has been much improved, with regard both to position and size of cabins, and a general air of comfort pervades them. Electric lighting has become general; and no doubt the efficient lighting of the holds and hatchways by this means has materially aided in the present rapid handling of cargo.

Having been compelled to pass over features of interest and instances of note, the Author hopes some of these will be brought forward in the discussion which this important national subject deserves. In conclusion he would point out that so great has been the advance in the development in cargo-steamers, that they are now able to make the longest passages with profit, and successfully compete with sailing vessels on their most favoured routes.

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9 JUNE, 1899.

## "Graving-Dock Blocks and Appliances."[1]

By ARTHUR JOHN MAGINNIS.

(*Abstract.*)

In a graving dock, the weight of a vessel when no longer waterborne was taken mainly upon the keel-blocks. In regard to these the points to be considered were:—the material of which to make them; the intervals between them; their design; and the maximum safe weight on each. For material, wood and cast-iron had each their special merit, while neither could boast immunity from accidents to vessels they had supported. The wider the spacing the better, in view of handiness for getting about the work, provided all risk of straining the hull was avoided. The design of the blocks should provide for their being readily removed, and for their being well hardened up again to take the weight when replaced. The maximum weight on each block should be kept low, as a precaution against too great a load coming on it when adjacent blocks were removed; the risk of such an occurrence in carrying out extensive repairs to the flat of the ship's bottom could be avoided by building up side cradles.

The primitive system of wooden side-shores, hardened up with wood wedges, had not yet been improved upon in practice. The adoption was suggested of horizontal steel shores, travelled out from the dock sides by hydraulic pressure, and securely locked in correct position against the ship's sides.

Lifting appliances, to meet the requirements of modern vessels when in dry dock, should include a travelling crane having a jib at least 65 feet above the dock bottom, with a clear outreach of from 50 feet to 60 feet, and capable of lifting 25 tons at least. Handy power-capstans, electric lighting, and electric power, were also among the appliances now desirable for graving docks.

[1] *The Engineer*, vol. lxxxvii. p. 641; *Engineering*, vol. lxvii. pp. 805 and 831.

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# "The Application of Mechanical Devices to the Riveting and Caulking of Ships; also the Material of Ship Rivets." [1]

By Robert Twentyman Napier, M. Inst. C.E.

(*Abstract.*)

Riveting machines used for shipbuilding were here stated to close the rivets either by pressure or by percussion. For those acting by pressure, whether hydraulic or pneumatic, no separate holder-up was possible; hence their use was limited by the depth of the gap, and as the gap increased, the weight increased in greater ratio. While successful from the outset in riveting up work brought to it, the hydraulic riveter had not always effected a saving in cost and time when applied on board ships upon the stocks; and this application had not become general in shipbuilding. Percussive riveters approached handwork in their action; they were driven by electric motors or by compressed air, and required a separate holder-up. Though more adopted in America, they were as yet only on their trial here; if found capable of doing satisfactory work, they had the advantage of convenience, simplicity, and lightness, but the disadvantage of noise. Countersunk rivets closed by machines were left with their points more or less cupped; and the points must either remain so, or must be chipped off if required to be flush with the plating. Caulking machines driven by compressed air or by electricity had done good work, where not debarred by refusal of men to use them; their success in America might yet be followed by their more general adoption here.

While rivets of good iron and good steel were alike accepted by some authorities, others recommended the latter material; and where prescribing quadruple riveting for iron rivets, they required only treble riveting for steel. Yet from various tests it would appear that iron rivets had shown an advantage over steel; and for smithy purposes Siemens-Martin steel was not so satisfactory as iron made by puddling.

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[1] *The Engineer*, vol. lxxxvii. p. 641; *Engineering*, vol. lxvii. pp. 806 and 831.

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## SECTION VI.—WATERWORKS, SEWERAGE AND GASWORKS.

8 JUNE, 1899.

# "The Use of Filtered Flood-Water."[1]

By MATTHEW WILSON HERVEY, M. Inst. C.E.

The use of flood-water is a subject on which opinion has much changed within the last few years; and in the remarks which the Author offers thereon, with the object of promoting discussion, he will confine himself chiefly to flood-waters of the Rivers Thames and Lea.

Within even recent years it was considered most undesirable to take water from a river when in flood, for at least ten days or a fortnight after the flood; but now many experts consider that flood-water may be taken without restriction, provided that it is afterwards subjected to subsidence and efficient filtration. It is a difficult matter to define what constitutes a flood; and to fix a limit as to the number of days after a flood that the water shall be allowed to pass to waste, before taking it into a subsidence reservoir, is a serious matter, especially when so large a quantity of water is required for the supply of London from the Thames and Lea, and a limit is fixed as to the minimum flow. Obviously any restriction must greatly reduce the number of days in the year on which water may be taken from the river, and must thereby largely increase the cost of providing storage. In the Author's opinion it may safely be left in the hands of the engineer to use his discretion as to when to reject flood-water. It is always to his interest to take the best water, because thereby expense in cleaning filters is saved. For a town dependent on its water-supply from a river, the water of which has to be filtered, it is doubtless desirable, if possible, to allow the first flush of flood-water to pass, before taking it into subsidence reservoirs; but it is not absolutely necessary. One flood may be followed comparatively quickly by another; and the effect of the first flood having been to cleanse the watershed, the water of the second is therefore in comparatively good condition.

[1] *The Engineer*, vol. lxxxvii. p. 587; *Engineering*, vol. lxvii. pp. 764 and 793.

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*Subsidence.*—Subsidence in large reservoirs has a powerful effect in purifying the water, and efficient filtration completes the process. The result of heavy rains, causing a river to be in flood, is to wash the vegetable and organic matter accumulated on the watershed into the river, and with it microbes; thereby the microbes in the water are enormously increased, but by reason of the large volume of water passing down the river the impurities in the water are in a greatly diluted condition. The water also carries a certain quantity of clayey matter in suspension. If flood-water is passed into a subsidence reservoir of large capacity, the slow velocity at which it passes from one end of the reservoir to the other, in order to be there drawn off to the filters, enables the matter in suspension to subside. In the worst of Thames flood-water the matter in suspension varies from only 1 grain to 1½ grain per gallon. As it settles it carries down the microbes with it. Sunlight also has a deleterious effect on microbes and kills them. Thus flood-water that contains thousands of microbes per cubic centimetre when taken into a large subsidence reservoir, contains only hundreds per cubic centimetre when drawn off at the opposite end. Flood-water is a good deal coloured, owing principally to vegetable matter; sunlight has a powerful effect in bleaching the colour, but it is a difficult matter to get rid of it entirely. It is perfectly harmless however, and the objection to it is merely sentimental.

*Filtration.*—The process of filtration of water requires the greatest amount of care, and its efficiency depends on several conditions: namely thickness of sand, fineness of sand, and rate of filtration. With these conditions fulfilled, and if a sufficient number of filters are provided, an excellent filtrate can be obtained, practically pure from microbes (that is, under 100 per cubic centimetre), even from flood-water passed direct on to a filter. Obviously however the filter becomes choked more quickly, and entails the expense of cleaning more frequently.

As an instance of passing flood-water direct on to the filters, Sir William Crookes, in giving evidence before the Royal Commission presided over by Lord Llandaff, stated:—"The large rainfall which took place in October last had the effect of suddenly washing into the rivers organic matter accumulated on the watershed during the three previous months; and as the reservoirs of the East London Water Company were almost empty at the end of September, the company was forced in October to use the Lea without the advantage of the purification resulting from proper storage in the reservoir. During this critical time we took extra

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pains to ascertain the character of the East London supply, and additional samples were regularly taken from various points in the district. It is highly satisfactory to report that in spite of the severe strain thus thrown on their filtering appliances, the clear water supply of East London has been bacteriologically better than it was during the months of August and September." This the Author thinks is highly instructive, as showing that flood-water can be dealt with efficiently when passed direct on to a filter.

The analysis of a sample of water taken by Sir Edward Frankland on behalf of the Local Government Board from the mains of the East London Water Works on 25th October 1898 gives an equally good result chemically:—

| | |
|---|---|
| Organic carbon expressed in parts per 100,000 . . . . | 0·107 |
| Organic nitrogen „ „ „ . . . . | 0·008 |

And the average of four samples, taken on the 1st, 10th, 18th, and 26th October 1898 by Sir William Crookes and Professor Dewar from the mains of the East London Water Works, gave—

| | |
|---|---|
| Organic carbon expressed in parts per 100,000 . . . . | 0·072 |
| Organic nitrogen „ „ „ . . . . | 0·013 |

During the same month a mean of 26 unfiltered samples taken from the River Lea contained 1,719 microbes per cubic centimetre; and a mean of 26 samples of the Lea water taken from the clear-water well of the East London Water Works contained only 13 microbes per cubic centimetre.

Reverting to the conditions to be observed for effecting efficient filtration, the thickness of sand necessary is to a certain extent governed by its degree of fineness; and the latter is varied by the greater or less admixture of sea-sand with the sand screened from the ballast of the district. Among the several London Water Works the thickness of sand on a filter varies from 4 feet 6 inches to 2 feet. The rate of filtration also varies among the several works, namely from $1\frac{1}{3}$ to $2\frac{1}{4}$ gallons per square foot per hour. The rate fixed as a safe rate of filtration by the late Colonel Bolton, Water Examiner appointed under the Metropolis Water Act 1871, was $2\frac{1}{2}$ gallons per square foot per hour; and this rate is acquiesced in by the present Water Examiner, General A. de C. Scott.

The longer a filter can be kept at work without requiring to clean the surface, the better; because shortly after it is set to work a gelatinous film is formed on the surface by the microbes arrested, and this gelatinous film is of great importance in pro-

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ducing a thoroughly good filtrate. The process of cleaning the surface obviously removes this film, which has to form again when the filter is set to work.

To show the efficiency of filtration in removing microbes during the year 1898, taking the mean of the average for each month of the twelve, the number of microbes in the unfiltered and filtered water was as follows:—

| | Microbes per Cubic Centimetre. |
|---|---|
| *Thames*— | |
| Unfiltered water | 4,672 |
| Filtered „ | 35 |
| *Lea*— | |
| Unfiltered water | 2,540 |
| Filtered „ | 26 |

The Author reproduces another instructive Table from a statement placed before the Royal Commission of 1892 by Sir William Crookes, showing the effect of flood-water on the chemical composition of the water supplied by the five companies deriving their supply from the Thames. The Table deals only with the water of floods that occurred from 1882 to 1892. Sir William

| Date. | Organic Carbon. | | Oxygen Required. | |
|---|---|---|---|---|
| | Actual Amount. | Average of 10 Years. | Actual Amount. | Average of 10 Years. |
| 1882. April | 0·080 | 0·100 | 0·035 | 0·039 |
| 1882. October | 0·110 | 0·096 | 0·065 | 0·042 |
| 1882. November | 0·205 | 0·120 | 0·093 | 0·058 |
| 1883. January | 0·155 | 0·121 | 0·065 | 0·056 |
| 1885. February | 0·127 | 0·123 | 0·063 | 0·056 |
| 1885. October | 0·089 | 0·096 | 0·039 | 0·042 |
| 1886. January | 0·129 | 0·121 | 0·070 | 0·056 |
| 1887. January | 0·138 | 0·121 | 0·072 | 0·056 |
| 1887. May | 0·093 | 0·098 | 0·038 | 0·044 |
| 1888. March | 0·113 | 0·113 | 0·045 | 0·047 |
| 1888. November | 0·114 | 0·120 | 0·068 | 0·058 |
| 1889. June | 0·095 | 0·098 | 0·041 | 0·047 |
| 1890. July | 0·016 | 0·100 | 0·053 | 0·049 |
| 1891. February | 0·184 | 0·123 | 0·085 | 0·056 |
| 1891. August | 0·079 | 0·088 | 0·047 | 0·049 |
| 1891. November | 0·177 | 0·120 | 0·105 | 0·058 |
| 1891. December | 0·169 | 0·124 | 0·085 | 0·060 |
| 1892. June | 0·085 | 0·098 | 0·033 | 0·047 |
| 1892. July | 0·080 | 0·100 | 0·035 | 0·049 |
| | 19)2·328 | 19)2·068 | 19)1·137 | 19)0·969 |
| Means | 0·122 | 0·108 | 0·059 | 0·051 |
| Differences | 0·014 | .. | 0·008 | .. |

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Crookes goes on to state:—"The above differences are utterly insignificant, and they show that in effect the flood-water is not less pure than the ordinary flow of the river water."

In conclusion the Author offers it as his opinion that, with proper subsidence and efficient filtration, flood-water may be taken without restriction, and be delivered to the consumer in thoroughly good condition, both chemically and bacteriologically. In all the bacteriological examinations made by the experts engaged in this matter, a pathogenic germ has never been discovered in the water supplied by the London Water Works.

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## "A Consideration of the Rate per Head per Day of Water-Supply in Different Towns, and of the Causes which increase or diminish it in particular instances." [1]

By James Watson, M. Inst. C.E.

In projecting new schemes of water-supply, in the maintenance and management of existing works, in the consideration of private Bills by Committees of both Houses of Parliament, and in the deliberations and Reports of Royal Commissions on water-supply, the "rate per head per day" appears as a question of prime importance. It is common knowledge that many well-informed authorities set up as a standard a certain number of gallons per head per day, which they contend ought to have a somewhat wide if not universal application; but in water-supply, as in other matters, "circumstances alter cases;" and to prescribe any more or less empirical unit of supply per head per day may mislead as to fact, and may be found unattainable in practice. The legitimate wants and demands of one town are rarely found to coincide, or even to approach coincidence, with those of any other town of the same or nearly the same population. The habits and character of the people differ, the composition of the water often differs largely; sanitary appliances, public-health requirements, trade demands, the number available of streams, wells, and underground waters, the relative number of baths, water-closets, hot and cold-water fittings per head of the population, the public, domestic and trade rates—these together form a chain, any link of which

[1] *The Engineer*, vol. lxxxvii. p. 587; *Engineering*, vol. lxvii pp. 764 and 795.

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might itself constitute a cause of difference in the quantity; and taken either in part or as a whole they are items absolutely essential to be included in the just and proper consideration of the causes which increase or diminish the rate of supply per head in different towns.

This may be illustrated by reference to one or two places. Bristol for instance, with 22 gallons per head per day, has a full and ample supply, while Glasgow takes 50 gallons per head per day. Here is a difference of 230 per cent.; yet the causes operating to produce such a contrast are not far to seek.

Glasgow supply from Loch Katrine is 1° of hardness, and for ordinary ablution and detergence the minimum of soap and the maximum of water are used. Out of a total revenue of £211,372, the revenue from non-domestic and trade supplies amounted last year to £120,136, which, taken at 4*d.* per thousand gallons, gives 7,208 million gallons, or nearly 20 million gallons per day out of a total consumption of 51½ million gallons per day, being 19 gallons per head per day of the whole population supplied; and in addition large unmeasured quantities of water are given free to public departments, for public-health purposes, swimming-baths, flushing sewers, washing streets and closes, &c.

In Bristol the conditions are practically reversed; the water is 22° of hardness, which means much soap and little water to form a lather tolerable to the skin, or having advantageous cleansing properties. Moreover water is not provided free in Bristol to any of the Corporation departments; and the price of 6*d.* to 1*s.* 6*d.* per thousand gallons, charged for non-domestic purposes, against 4*d.* charged in Glasgow, tends to limit the trade demand.

Bradford, within the city boundaries, consumes 40 gallons per head per day, of which 20 gallons are used for trade purposes; and this quantity does not include water for public-health purposes, watering streets, &c. But contrasted with Glasgow, which is a water-closet town where water-closets and baths are included in the domestic rate of 6*d.* per £ on the rental, Bradford like many other English towns does not compare well. Bradford as yet can hardly be called a water-closet town, having only one water-closet to each 16 persons, and only one bath to each 38 persons; while, in addition to the domestic rate, extra charges are made for baths and water-closets. Comparing Bradford with Bristol, the whole supply per head of Bristol would not do more than meet the trade and public-health wants of Bradford.

The supply to London is about 33 gallons per head per day, Edinburgh 38, Dublin 38, all residential cities; to Liverpool 29¾,



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Manchester 28, Belfast 35, Dundee 48, Aberdeen 43, all commercial and manufacturing centres; and if preventable waste be eliminated, then it follows that these differences are the results of the legitimate wants of the inhabitants, or at all events of their free and unrestricted use of the water.

Waste, preventable and unpreventable, obtains to a greater or less degree in connection with every waterworks distribution; and where proper regulations are in force, it is the only cause of increased consumption which can be dealt with directly by the waterworks engineer. It must not be inferred that those regulations which compel the use of a 2-gallon flush for a water-closet err in parsimony, nor that those which allow a 3-gallon flush err in extravagance; yet this important difference is but one of the many authorised and legitimate differences which bear directly on the rate of supply per head. Hence, apart from preventable waste, all other differences between one town and another in supply per head per day are but proper measures of the wants of the inhabitants. In this country, fortunately and wisely, the large congested centres of population are not restricted in the free use of water for culinary and domestic purposes; and the Author trusts the day is far distant when an incentive to a niggardly use of water, with its accompanying danger to public health and cleanliness, shall be afforded by the sale of water by measure for domestic use. So long therefore as unrestricted constant service is given, the supply per head per day in each town will be measured by the facilities for using water, and by the careful or careless habits of the people in its use.

Respecting preventable waste, and the numerous methods employed for its detection and control, suffice it to say that in this, as in many other things, prevention beforehand, where practicable, is better than cure. Constant systematic inspection, attention to the covered service mains, to the insulation of house-service pipes, to the strength of pipes, length of lever, diameter of ball, seats of taps, &c., relatively to maximum working pressure, the eradication of old and worn fittings within a fixed limit of time, and the careful examination and testing of all new water-fittings, will, if carefully carried out by the waterworks officials, tend to minimise the one wholly unsatisfactory cause of increase in the water-supply of every town, namely waste. General statements that 25 gallons or 30 gallons per head per day constitute a full supply should not be accepted; these rates have been found ample in many towns, and totally inadequate in many others. While 30 gallons would indicate great waste in Bristol,

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the same quantity in Glasgow or Bradford would mean an utterly insufficient supply, even though waste did not exist.

Although the Author cannot have stated anything new in these remarks, the subject affords ample scope for varied opinions, which will not fail to show that, in the whole domain of social economy, nothing has been a greater benefit to man than an abundant supply of pure water to every house.

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## "Sewage-Sludge Disposal by Natural Agencies."[1]

By German Sims Woodhead, M.D.

This matter of sewage-sludge disposal practically constitutes the crux of the sewage question; for recent investigations and experiments have proved that it is a comparatively easy matter to bring about the disintegration of organic matter held in solution, especially if the solution be sufficiently dilute. The proportion of sewage matter held in suspension to that in solution is comparatively small; but, owing to the fact that it is solid, there has been a difficulty in dealing with it, unless it could be removed from the sewage by sedimentation, precipitation, and screening, and could be buried, when the organisms of the "living" soil would rapidly bring about its disintegration. It has to be borne in mind that sewage sludge consists almost entirely of organic matter; and that, if any large amount of inorganic matter finds its way into sewage, it is from road surfaces or from yards, or is washed from the surface of loose soil. Such inorganic matter can be got rid of only by sedimentation; and, unless it is got rid of, there can be no hope of dealing successfully with the sludge, inasmuch as no means of disintegration at present known will deal with quartz or clay, and the presence of these substances, especially the latter, must necessarily interfere greatly with any process of bacterial disintegration that has hitherto been devised.

With organic solid matter, however, it is quite possible, the Author believes, to obtain good results. In nature, organic matter is dealt with not only in the soil, but also on the surface of the soil. If any organic matter be left exposed, say on a gravel surface, it will be observed that, although there may be a hard outer film formed in dry weather, as is the case with a mass of cow-dung, the centre, at first moist, in time becomes exceedingly

[1] *The Engineer*, vol. lxxxvii. p. 588; *Engineering*, vol. lxvii. pp. 765 and 795.



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soft, and gradually diminishes in quantity: so that, when rain comes, such a mass, though hard on the outer surface, is rapidly washed away. In showery weather the process goes on with even greater rapidity. What is it that takes place under these conditions? First of all there is in the moist mass an enormous development of anaerobic organisms, which, utilizing some of the material as food, produce a series of substances that have the power of digesting or dissolving a considerable portion of the organic matter. In this process are also produced gaseous and liquid substances, of which the former escape into the atmosphere, often giving rise to foul smells; the latter soak into the soil, and are there attacked by other organisms. In wet weather, or when the mass remains moist, there is brought into play in addition the action of a series of aerobic organisms, which assist in the oxidation of the products formed by the organisms in the substance of the mass. Under these conditions there is a more free escape of the gaseous products, and a washing away of those products which interfere with the activity of the micro-organisms. In fact, all the soluble matter is washed away, and the mass of dung disappears, with comparative rapidity. If this mass of fæces be buried in the soil, the process may go on still more rapidly; and it will be found that the vile smelling gases are so rapidly oxidised by the aerobic organisms which grow near the surface of a porous soil that not a trace of odour is met with.

All the methods of treating the solid matter of sewage that have hitherto achieved any success are those in which these processes of nature have been applied under controlled conditions. These conditions must of course to a certain extent be artificial; but the nearer they can be brought to those observed in nature, the more successful will they be in disintegrating or getting rid of solid organic matter. In a cesspool, which, as is known, seldom requires to be cleared out, the solid substances of sewage are gradually but surely disintegrated; but the great disadvantage of the cesspool is that the enormous amount of gas formed must find its way out somewhere; whilst in addition, as the substances become liquid, leakages take place into the soil in all directions, so that a large quantity of imperfectly oxidised material accumulates in the neighbourhood of the tank, the sodden ground allowing of no aeration.

In the Scott-Moncrieff disintegrating tank and in the Exeter septic tank, the main part of the work done is this disintegration of solid material by anaerobic bacteria. The solid material remains sufficiently long in contact with micro-organisms to be broken down: in fact it remains there until it is broken down.

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There is this additional advantage, that there is constantly flowing over the surface of the breaking-down sludge a liquid in which the gases are dissolved as they arise from the decomposing organic matter, and which carries away a large proportion of the products of the life activity of these micro-organisms; the organisms are thus left free, ridded as they are of the effete products to which they give rise, to go on with their work energetically; indeed this flow of water acts to a certain extent like a shower of rain, except that the sewage does not contain oxygen, whilst the rain does. It is of course impossible for oxidation to go on at this stage in a septic tank; and therefore, in default of special arrangements, offensive smells may be developed. As soon however as oxidation commences, as it must do wherever aerobic organisms are able to live, these offensive gases become rapidly transformed into non-smelling gases, frequently of much simpler composition, but always containing a considerable proportion of oxygen.

The disposal therefore of solid organic matter or sewage sludge in these artificial tanks, if the process is to be successful, the Author considers must go on as nearly as possible under the conditions met with in nature. Rapid disintegration by anaerobic organisms must be brought about, all soluble and gaseous matter must be washed away as soon as formed, and must be subjected to aeration, oxidation, and the action of aerobic organisms. Only thus can the solid matter of sewage be best dealt with. By sedimentation in catch-chambers, all inorganic material must as far as possible be separated out. In the case of clay it is difficult to do this; and the better plan therefore is to prevent, as far as possible, surface water that has not undergone sedimentation from getting into the sewage. It does not matter how concentrated the material to be acted upon may be; but it is highly important that, on the one hand, the supernatant liquid should not contain too large a proportion of organic matter, and that, on the other, it should not contain too large a quantity of effete products—ammonias, methylamines, and the like—which interfere with the action of the anaerobic organisms, since no organisms are able to do their work in the presence of too large quantities of their own effete products.

How far the rapidity of oxidation may be increased by the use of oxidising substances is an important question, but one into which it is impossible to enter in so brief a note.

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9 JUNE, 1899.

# "The Recovery of Residual Products from Coal-Gas during the Process of Purification." [1]

By WILLIAM FOULIS, M. Inst. C.E.

The impurities removed from crude coal-gas during the process of purification have, almost without exception, a commercial value; and it is the duty of the gas engineer so to design the apparatus and to conduct the purifying operations that no saleable impurity may be lost, but that all may be recovered in a form to yield the highest value. The importance of this subject to the gas manufacturer is best shown by the statement that the amount derived from the impurities removed from coal-gas during the process of purification, which were at one time thrown away or destroyed as having no value, is, in this country alone, not less than £1,500,000 per annum; consequently they are no longer considered merely as impurities necessary to be removed, but as residual products, which it is one of the aims of the gas manufacturer to obtain.

The residual products or impurities which have a commercial value may be briefly described as the liquid hydro-carbons and the nitrogenous compounds; perhaps also there may be included with these the sulphur recovered when oxide of iron is used for purification. In this note the nitrogenous compounds only can be referred to, of which the most important is ammonia. In his Presidential Address in 1896 to the Institution of Gas Engineers [2] the Author pointed out that, of the total amount of nitrogen in the coal used in gas manufacture, only about 15 per cent. was evolved in the form of ammonia, and that more than 50 per cent. of the remainder was left in the coke; whilst in other methods of carbonising, more especially in shale-oil retorts, at least double the quantity of ammonia is obtained.

In 1897 a Paper was read before the Institution of Civil Engineers [3] on the Mond gas-producer, in which it is stated (page 192) that in this method of gas production there is obtained a quantity of ammonia equivalent to 90 lbs. of sulphate of ammonia per ton of coal, a quantity four times greater than that

[1] *Engineering*, vol. lxvii. pp. 807 and 832; *The Journal of Gas Lighting*, vol. lxxiii. p. 1554.

[2] Incorporated Institution of Gas Engineers, 1896, vol. vi. pp. 27 and 28.

[3] Proceedings 1897, vol. cxxix. p. 190.

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obtained in most gasworks. Whether similar results are to be got in the ordinary process of gas manufacture may be doubtful; but something may be done to recover at least a portion of the ammonia which is at present lost. The method of heating retorts by gas generated in a central producer and conducted in flues to the retort benches is almost certain to be extensively adopted in the near future. Already practical experiments on a large scale have been made at several works with highly encouraging results. The Author's experience leads him to believe that complete success awaits only the overcoming of certain minor difficulties, which do not appear formidable. This method of heating possesses many advantages, which it is unnecessary now to refer to; not the least of them is that it would then be possible to recover the nitrogen in the form of ammonia from a large proportion of the coke. A modification of the gas-producer devised by Dr. Mond would probably be adopted; and after condensation and scrubbing, the gas would be stored in holders for distribution under constant pressure to the retort settings.

In his Address above referred to, the Author has pointed out (page 29) that about 0·027 per cent. of the nitrogen was evolved as cyanogen. The recovery of this impurity has of late years become of considerable importance to the gas engineer, more especially as the use of cyanide for the recovery of gold from refractory ores has so enormously increased the demand for both cyanide of potassium and cyanide of sodium. When crude gas is passed through moist oxide of iron, it combines with a portion of the iron, forming a ferro-cyanide. This is perhaps the simplest method of recovering the cyanogen; but it is also the least satisfactory, because it is almost impossible by this means to recover the whole of the cyanogen, or even any definite percentage of it, and also because of the large mass of material that has to be dealt with in order to obtain the comparatively small quantity of ferro-cyanide.

There are at present two methods in practical operation at different gasworks for the direct recovery of cyanogen from crude coal-gas. In the one method a solution of an iron salt, usually sulphate of iron, is run into an ordinary rotary ammonia scrubber-washer; the result is the formation of a ferro-cyanide of ammonium, an unstable compound which has no commercial value. The liquor from the scrubber is afterwards treated for the recovery of the ammonia, and also of the cyanogen in the form either of Prussian blue, or of the ferro-cyanide of potash or soda. The Author has no practical knowledge of this process or of the

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results obtained; but he believes that the cyanogen in the crude gas produced from about 1,000,000 tons of coal per annum is recovered more or less completely by this method.

The other process for the direct recovery of cyanogen from crude coal-gas is that adopted by the Author, which may be briefly described as follows. Scrap-iron is dissolved in hydrochloric acid, forming a chloride of iron. The latter is afterwards treated with carbonate of soda, whereby carbonate of iron is precipitated in a fine state of subdivision. This precipitate is added to a solution of carbonate of soda in proper proportions, and the two are mixed by stirring in a vessel fitted with a mechanical stirrer. The mixture is then run into a scrubber so constructed that it is kept in a constant state of agitation, so as to prevent the iron depositing. It is not necessary here to enter into the various chemical changes that take place when crude coal-gas, from which all trace of ammonia has been removed, is passed through the scrubber containing this mixture. It is sufficient to state that the ultimate result is a solution of ferro-cyanide of soda, together with a small percentage of insoluble ferro-cyanide, the amount of which depends on the efficiency of the apparatus to maintain the iron in suspension in equal quantities throughout the liquid. By this means the whole of the cyanogen may be recovered from the crude coal-gas, the amount recovered being usually equivalent to 4 lbs. of ferro-cyanide of soda per ton of coal carbonized. The mixture of carbonate of iron and soda is run in at the outlet end of the scrubber, and flows onward to the inlet end. When the percentage of free alkali in the ferro-cyanide liquor at the inlet end of the scrubber has been reduced to as low a point as possible—usually about 8 per cent. of the total alkali used—it is run off. The liquor containing the soluble and insoluble ferro-cyanide may then be allowed to settle; and the clear portion may be run off, evaporated, and crystallized. The insoluble ferro-cyanide may be recovered in a soluble form by adding caustic alkali. As the ferro-cyanide liquor usually contains a certain quantity of tarry matter, it is preferred to evaporate the whole to a dry cake, which can be afterwards dissolved and treated as above described.

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# "Labour-saving Appliances in Gasworks."[1]

By CHARLES CLAUDE CARPENTER, M. Inst. C.E.

The consumption of coal for gas-making in the United Kingdom is about 13,000,000 tons per annum, of which quantity the three Metropolitan companies use upwards of 3,250,000 tons. By the action of the sliding scale, which automatically regulates their dividends in accordance with the price charged for gas, the companies have a direct interest in keeping the cost of this as low as possible. A saving of 1*d.* per ton upon the coal carbonized in London is equal in round numbers to £13,500 per annum. Inasmuch as with hand-labour the cost of unloading coal, carbonizing, and handling the resultant coke, is approximately 4*s.* per ton of coal, the possibilities and economies of substituting machinery will be apparent. In the majority of London gasworks, coal is brought alongside in ships or barges, unloaded by steam or hydraulic cranes, and deposited in the retort-houses or coal stores as required. The cost for hand-labour is as follows per ton:—

| | *d.* |
|---|---|
| Fillers | 3 |
| Tippers | 0½ |
| Crane-driver | 0½ |
| Truckmen | 0¾ |
| Total | 4¾ |

By means of self-acting grabs, it is possible to reduce the first item considerably, and to eliminate the second altogether. The figures will then be as follow per ton:—

| | *d.* |
|---|---|
| Filling and trimming for grab | 0¾ |
| Crane-driver | 0½ |
| Truckmen | 0¾ |
| Total | 2 |

The grabs chiefly used for the purpose of unloading coal in the Thames are the invention of Mr. T. Hone, of the Thames Ironworks, and their use is rapidly extending among the Metropolitan gas and other companies. There is however a slight set-off against the saving in labour stated above, owing to the increased

[1] *Engineering*, vol. lxvii. pp. 810 and 832; *The Journal of Gas Lighting*, vol. lxxiii. p. 1557.

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dead weight of the grab over the ordinary skip. This necessitates stronger and more powerful cranes, as well as the continued use of extra power to work them. But the latter consideration does not amount to much, as hydraulic-power machinery may now be regarded as an essential part of the equipment of a modern gasworks.

The low cost of transferring the coal from the crane hoppers is due to the fact that, in the instance given, the retort-house is end on to the waterway by which the coal is brought, and is separated therefrom by a space only large enough to contain the crane and its loading hoppers. From the latter the coal falls into trucks propelled by hand along rails placed above the longitudinal bunkers, from which it is fed into the retorts.

The arrangement of the retort-house, wherein all the raw material and 75 per cent. of its products are handled, bears largely upon the economical working of a gasworks. In the new works of the South Metropolitan Company at Old Kent Road, designed by Mr. George Livesey, M. Inst. C.E., the retort-houses and adjacent coal stores are arranged all in parallel lines, and each of them end on to the Surrey Canal. The coal is unloaded at the ends abutting on the canal; and at the opposite ends the coke and breeze are taken by conveyors to the storage ground, which occupies relatively to this end of the retort-houses a position corresponding with that of the canal at their other end. This arrangement reduces to a minimum the cost of handling both coal and coke. The characteristics of this design are followed at the new East Greenwich works of the same company.

Coal should be placed within the retort-houses in such a position that it can be most economically fed into the retorts; and it is suggested that the best method is to provide longitudinal bunkers facing the mouthpieces, with one or more shovelling shelves. With such an arrangement, hand-stoking is carried on in the South Metropolitan works at the cost given below. In this and the following comparisons, retort stoking is taken to mean charging and drawing the retorts, cleaning lids and pipes, and furnace feeding.

TABLE OF HAND-STOKING.

| | |
|---|---|
| Three stokers at 6*s.* per shift of 8 hours . . . . .<br>One scoop-driver at 6*s.* 4*d.* per shift of 8 hours . . . | 24*s.* 4*d.* |

Work done, eighty mouthpieces at 3 cwts. charge per mouthpiece = 12 tons.

$$\frac{24s.\ 4d.}{12\ \text{tons}} = 24{\cdot}33d.\ \text{per ton.}$$

At the same works the hydraulic-power stoking machines,

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designed by Sir William Arrol and Mr. William Foulis (MM. Inst. C.E.), work 220 retorts. One set of machines charge and draw 293 mouthpieces per 8-hour shift. The machine-gangs, of which there are six, are each made up of six men, doing similar work to that of the hand-gang, but the weight of the charge is increased to over 3½ cwts. per mouthpiece.

TABLE OF HYDRAULIC-POWER STOKING.

Six stokers at 6*s*. per shift of 8 hours = 36*s*.

Work done, 293 mouthpieces at 3½ cwts. charge per mouthpiece = 51·275 tons.

$$\frac{36s.}{51 \cdot 275 \text{ tons}} = 8 \cdot 42d. \text{ per ton.}$$

In this case there must be added maintenance of the machines, interest &c. on capital outlay, fuel, oil, water, &c. The two sets of machines were erected for £3,200; and, assuming they work for 300 days per annum, they would deal with 92,400 tons of coal. Taking interest and depreciation at 10 per cent. on the capital outlay, this comes to 0·83*d*. per ton. Reckoning 2¼*d*. per ton for maintenance, and ½*d*. for fuel and water, oil and waste, &c., the total addition amounts to 3·58*d*. per ton. Hand-stoking requires for maintenance of tools &c. about ½*d*. per ton.

With the machines, the duty of the retorts is increased in the proportion of about 3 to 3½. With hand-stoking, 220 retorts would carbonize 264 tons per day against 308 tons by machine, a difference of 44 tons. The extra number of 36 retorts would be required with hand-stoking for this difference, entailing an expenditure of say £75 per retort, or £2,700. To pay 7½ per cent. on this would require £202 10*s*. 0*d*. per annum, equal to 0·52*d*. per ton carbonized by the machines, with which amount they must be credited.

An alternative to machinery is inclined retorts; of these there are two sets at Bankside. A set of 144, each 20 feet long, cost £100 per retort.

TABLE OF INCLINED-RETORT STOKING.

Four men at 7*s*. 1*d*. per shift of 10 hours = 28*s*. 4*d*.

Work done, 144 retorts at 6 cwts. per retort = 43·2 tons.

$$\frac{28s.\ 4d.}{43 \cdot 2 \text{ tons}} = 7 \cdot 87d. \text{ per ton.}$$

Taking the extra cost of inclined retorts over horizontal at £25 each = £3,600, interest and depreciation at 7½ per cent. would come out at 1·25*d*. per ton, 51,840 tons being carbonized in 300

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days. To this must be added ½*d.* per ton for maintenance of stoking appliances and hopper-feeding machinery.

The figures of the three plans may be summarized as follows:—

| Items. | | Hand-Stoking. | Hydraulic Stoking. | Inclined Stoking. |
|---|---|---|---|---|
| | | *d.* | *d.* | *d.* |
| Labour | per ton | 24·30 | 8·42 | 7·87 |
| Stoking tools | ,, | 0·50 | .. | 0·50 |
| Wear and tear | ,, | .. | 2·25 | |
| Fuel, oil, water, &c. | ,, | .. | 0·50 | 0·10 |
| Interest, &c. | ,, | .. | 0·83 | 1·25 |
| | | 24·80 | 12·00 | 9·72 |
| Less value of increased output | ,, | .. | 0·52 | .. |
| | | 24·80 | 11·48 | 9·72 |

Some of the 2¼*d.* spent under the head of wear and tear in hydraulic stoking was applied to perfecting the machines; and it is expected that this figure will eventually be reduced below 1½*d.* A hand-stoked retort will last an average of 2,400 working days of 24 hours, and will carbonize 2,880 tons of coal. With machine-worked retorts there is every reason to think the equivalent of about 2,000 days will be reached. It seems probable that the life of inclined retorts will be considerably less, and the extra cost of their renewals important.

Something more however is required of retort-house plant than merely to act as an apparatus for handling so many tons of coal and coke at a minimum of cost. It must yield a maximum of gas and "sperm value." This machinery does to even a greater extent than hand-stoking, since the proportion and contour of the "charge" can be maintained with unfailing regularity. With inclined retorts the case is different. The coal must not only be evenly charged in the retort, but it must also remain evenly distributed during carbonizing. With a margin of impetus, damp and cohering fine coal can be laid as evenly as if large and dry. But more than half the varieties of Durham coal slip or creep during carbonization. Watering the coal, and storing it for a twelvemonth or so, have been suggested as remedies. If it is assumed that gas as it leaves the retort-house is worth a penny per 100 cubic feet, a loss in make would be a serious set-off, if it reached 300 cubic feet per ton.

There remains the question of handling coke, of which the pro-

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duction for sale is more than half the weight of the original coal. At the Vauxhall works, 5¼ acres in area, 60,000 tons of coke and breeze are handled yearly by small locomotives and wagons running on a narrow-gauge railway. The cost of labour has been thereby reduced from 1*s.* to 3*d.* per ton. At the Old Kent Road works, where the coke storage-ground is at one end of the retort-house, wire ropes, driven by a gas-engine, are used to haul two trains of wagons up an incline of 1 in 2 to an elevated road where the coke is tipped as desired. The cost of handling, including quenching, is 4½*d.* per ton.

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## SECTION VII.—APPLICATIONS OF ELECTRICITY.

7 JUNE, 1899.

# "Methods of Electrical Transformation." [1]

By JAMES SWINBURNE, M. Inst. C.E.

The only transformer to be considered a few years ago was the ordinary stationary alternating transformer; but with modern developments of extra-urban supply stations, and with general supply systems, the most important transformer may soon be one of the numerous forms of dynamotor. A system of electrical transformation means a system for transforming energy at the power-house into energy delivered to the consumer, and is therefore a large subject.

The general fashion is to generate triple currents, and to transform them into direct currents locally. There are other possible methods however, such as generating high-pressure direct currents, generating single or double currents, with transformation into any sort desired at the supply end. As regards the generators, the direct current has the objection of high-pressure commutator, and perhaps somewhat extra cost. The direct current however was originally set aside, because it demanded a dynamotor instead of a stationary transformer; but now that the rival systems demand the same when direct-current supply is contemplated, direct-current generation requires reconsideration, at least for moderately high pressures. It has never had fair play. The extra cost of the dynamos is a small matter, and their efficiency and the efficiency of the whole system may be higher.

In long-distance work the most important question is the leads, consisting of copper and insulation. All sorts of precise statements as to the copper needed by each system are made; but they are meaningless, unless the assumptions are stated on which they are based.

Taking first the question of copper only: the first consideration in a comparison is, What pressure is to be used? The next, Is it

[1] *The Engineer*, vol. lxxxvii. p. 574; *Engineering*, vol. lxvii. pp. 758 and 767; *The Electrical Engineer*, vol. xxiii. p. 719; *The Electrical Review*, vol. xliv. pp. 966 and 999; *The Electrician*, vol. xliii. p. 272.

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the maximum, the effective, or the mean? The third, Is it as compared with the earth, or with other parts of the circuit? It will be assumed that in all alternating currents the maximum pressure has to be taken, as being the critical pressure in regard to insulation rupture, and especially in regard to life. For comparison a set of definite cases may be taken: say 10,000 volts, and 2 square centimetres of copper, at a density of 200 amperes per square centimetre.

*Case* 1.—The system earthed at a middle point, no wire to be more than 10,000 volts from earth. The direct current is then 20,000 volts and 200 amperes. The single alternating current has 7,100 volts each side. The double alternating current has the same, but has its thick wire grounded, and has smaller currents. The triple current has a middle point earthed; and though its wires never go over 10,000 volts above earth, they go more from each other.

*Case* 2.—One conductor to be earthed. This is a condition that may be compulsorily enforced, and practically means concentric mains with little insulation on the outside conductor. In this case the direct current has 10,000 volts and 200 amperes, the single alternating 7,100 and 200, the double alternating is as in case 1, but the triple current comes down considerably.

*Case* 3 is where the difference between no two conductors exceeds 10,000 volts.

These results may be tabulated as follows:—

| Current. | Output in Kilowatts. | | |
|---|---|---|---|
| | Case 1. | Case 2. | Case 3. |
| Direct . . . . . | 4,000 | 2,000 | 2,000 |
| Single alternating . . . . . | 2,824 | 1,412 | 1,412 |
| Double „ . . . . . | 1,650 | 1,650 | 1,170 |
| Triple . . . . . | 5,000 | 2,824 | 2,824 |

In all these cases the triple current is best, and the direct comes second. In all of them the leads have a total area of 2 square centimetres, and a density of 200 amperes per square centimetre.

The next question is insulation, to which little attention is generally given. Insulation resistance must be discarded as a criterion, and it must be remembered that the disruptive stress is not uniform throughout the insulation. The thickness of insulation has been calculated out on the assumption that at no part of the dielectric must there be a stress exceeding 20,000 volts per

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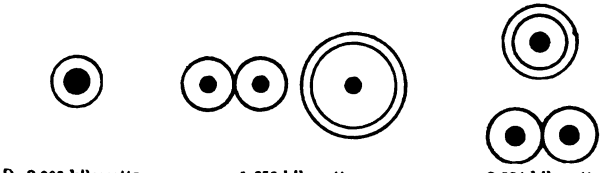
centimetre. It is unnecessary to give the calculations. The formula comes out—

$$\log R = \frac{E}{S\,r} + \log r,$$

where R is radius of insulation, E is the pressure, S the maximum stress, and $r$ the radius of the wire. It must be insisted on that this is only an assumption. In practice cable-makers do not

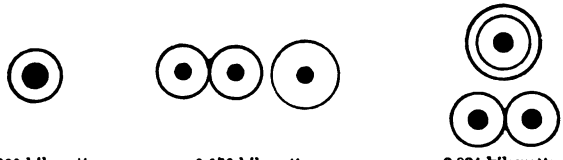
D. 4,000 kilowatts. 1,650 kilowatts. 5,000 kilowatts.
A. 2,824 ,,

Case 1.—10,000 volts from Earthed Point.



D. 2,000 kilowatts. 1,650 kilowatts. 2,824 kilowatts.
A. 1,412 ,,

Case 2.—10,000 volts from Earthed Conductor.



D. 2,000 kilowatts. 1,170 kilowatts. 2,824 kilowatts.
A. 1,412 ,,

Case 3.—10,000 volts between Conductors.

follow such a rule as this. It is true only for homogeneous dielectrics. Cable-makers vary their homogeneity by the unwilling introduction of spangles and other foreign bodies. It is difficult to find out on what principles they work; they indulge largely in secret processes, which is always a suspicious proceeding; and it may be hinted by others that they work in a haphazard rule-of-thumb way, without any principles whatever. Some of the specimens here exhibited of cables are caricatures. A small solid conductor causes such a sudden fall of potential at its surface that

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a larger tube takes a covering of smaller diameter. Except the first and third examples in case 1, the cables have external earthed conductors.

The figures tabulated go to show broadly that, on the assumption made, the direct and single-alternating currents are preferable, as far as cost and convenience of insulation go. Distances are getting longer and pressures higher, and the cost of the cables is becoming a more and more important matter, demanding the most careful consideration.

The whole question of loss by dielectric hysteresis is left out of this consideration. The Author's own experience in this matter is with condensers rather than with cables; but if there had been time it would have been considered too. It is important, and this way of losing power is peculiar to alternating and multiple currents.

As to cost of transformers, if direct current is needed for distribution, there is not much to choose; if alternating is to be delivered, the single alternating system has a clear superiority in all respects.

As to convenience in measurement and handling, the direct current is far ahead, closely followed by the alternating; the double and the triple come in a long way behind, if at all. Capacity effects, and all sorts of inductive effects, are drawbacks peculiar to alternating and multiphase work; they are more troublesome in multiphase work. Bare copper conductors ought to be considered with reference to incipient discharge at the surface, and to waste of power in the air. A tubular conductor is thus preferable, and sometimes necessary, instead of a solid rod of the same cross sectional area.

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## "Some Non-Integrating Electric Meters." [1]

By Prof. WILLIAM EDWARD AYRTON, F.R.S., Assoc. M. Inst. C.E.

*Materials.*—The five most important metals employed in the construction of electric meters are copper, iron, steel, phosphor-bronze, and some alloy of high resistivity. A few years ago copper of

[1] *The Engineer*, vol. lxxxvii. p. 611; *Engineering*, vol. lxvii. pp. 757 and 768; *The Electrical Review*, vol. xliv. pp. 965 and 997; *The Electrical Engineer*, vol. xxiii. p. 721; *The Electrician*, vol. xliii. p. 273.



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98 per cent. conductivity (Matthiessen's standard) was considered good; now it is stated that copper of 105 per cent. conductivity can be obtained commercially from Mouchel of France. The great increase in the electric conductivity has been attributed to greater density of the material, but there seems to be considerable doubt about this; and it is desirable to try whether a still further electric improvement, possibly even a relatively large one, might not be produced by using much greater care in removing the last traces of impurities. It is also important to find out exactly how the variation of resistance with temperature increases with increase in the electrical purity.

Soft iron for needles of electrical instruments should have small residual magnetism and small coercive force; while both these qualities should be large in steel for permanent magnets. A large magnetic improvement has been effected in commercial soft iron during the last few years, and even steel can now be purchased in ingots having a far smaller coercive force than the so-called soft iron practically employed for electric apparatus six or seven years ago; and, by constructing the meter so that the magnetic induction is kept low, soft-iron instruments may be used for measuring alternating currents and pressures with fair accuracy. It should be remembered however that, although the number of turns and the maximum scale reading may correspond with a number of ampere-turns which produce only a small induction with a sine- or a flat-wave, such instruments may read wrongly if the wave be peaked. A satisfactory compensation for variation in the frequency is effected by shunting the instrument with a self-induction; and experiments should be made for devising some such contrivance to compensate for the wave having a peak.

The manufacture of steel magnets has much improved during the past few years, as indicated by the following results obtained from tests on steel magnetized with a force exceeding 200 :—

| Metal. | Residual Magnetism. | Coercive Force. |
|---|---|---|
| 1885. Oil-hardened steel tested by Dr. John Hopkinson . . | 11,300 | 12 |
| 1893. Glass-hard pianoforte wire tested by Professor Ewing | 9,500 | 45 |
| 1898. Molybdenum steel tested by Madame Curie . . . | .. | 85 |

This marked increase in the coercive force, which is of great importance in preserving the constancy of permanent-magnet measuring instruments, has been brought about partly by im-

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provement in the composition of the material, and partly through greater experience having been gained regarding the proper way of hardening magnets. Still greater improvement may certainly be anticipated.

In instruments employing a spring control, and in which, for magnetic reasons, steel cannot be used, phosphor-bronze is the best elastic metal; but it is far excelled by quartz as regards the absence of sub-permanent set. It is highly desirable to find a really satisfactory method of coating quartz with even a metallic layer of sufficient conductance to serve as the flexible electrode for an electro-static voltmeter using a spring control; but, better still, some metallic alloy possessing the mechanical properties of quartz is well worth seeking. Alloys possessing higher and higher resistivities and smaller and smaller temperature-coefficients are being constantly brought to notice; but no one seems to be seeking for a substance with a small temperature-coefficient and a small resistivity, although this is the kind of substance that is needed for many purposes: as, for example, for winding voltmeter coils, and the bobbins of moving-coil instruments used with a shunt for the measurement of large currents.

*Galvanometers.*—The moving-coil instrument has effected a revolution in galvanometry, and where low resistance and short period are desired it greatly surpasses the moving-needle type. No moving-coil galvanometer however has yet been constructed that will even indicate the existence of the small currents which certain moving-needle galvanometers will measure accurately. Development of the moving-coil galvanometer is at present limited by the comparative smallness of the field produced by a permanent magnet, by the limiting thinness that can be given to the strip of metal used for the suspension, and by the slight trace of magnetism that remains in the so-called non-magnetic materials used in constructing the coil, even after the application of the best method for freeing them from magnetism. In view however of the great improvements that have been introduced into moving-coil galvanometers during the past few years, and of the fact that a given volume of wire possesses such an enormously greater value in the moving-coil than in the ordinary moving-needle instrument, it may not be too sanguine to look forward to moving-coil galvanometers rivalling moving-needle galvanometers for all purposes.

*Ammeters and Voltmeters.*—Instruments depending on the action of one coil on another without iron generally use a working field of about 50. Therefore, since the field on a central-station switch-



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board often exceeds 20, the disturbance may be great. Indeed the error arising from the current in the leads alone of such an instrument may be serious. The importance is here manifest of using copper of much higher conductivity than can at present be obtained: so as to employ many more convolutions of wire, without increasing either the volume or the resistance of a coil. Some soft-iron needle instruments have also fields not exceeding about 70, and are therefore quite useless for central-station work, unless protected in special ways with soft-iron magnetic shields.

The field in which the coil of some moving-coil instruments turns is as high as 1,200, and it might be expected that small stray fields would produce no error. But, as a matter of fact, the iron pole-pieces, and especially the iron core, concentrate the stray field on the coil; so that a stray field of only 0·5, when parallel to the field of the instrument, may produce an error of 0·4 per cent., or nearly ten times as great as the ratio of the fields alone would lead one to expect. The employment however of an astatic pair of narrow coils without an iron core greatly reduces this error.

For measuring large alternating currents it is desirable to employ a small transformer, giving a maximum secondary current of some 10 amperes, which can be easily led to an ammeter at a safe distance from the main cable; and, by keeping the resistance of the secondary circuit low, the transformation ratio will not be affected by changes of frequency. The best way at present of measuring small alternating currents is by means of an electrostatic voltmeter shunting a non-inductive resistance.

Electro-static voltmeters have practically no errors due to stray magnetic fields, unless they are rapidly alternating. In the latter case, unless the needle and inductors be properly subdivided, eddy currents may be induced, and a disturbing force be introduced. The error due to impedance is practically zero, because the capacity of a dead-beat electro-static voltmeter with a 12-inch pointer need not exceed about thirty-millionths of a micro-farad. Pivot-friction and brush-discharge between the needle and inductors introduce the greatest troubles, and it is difficult to obtain as much damping as is desirable. Coating the inductors with mica, enamel, &c., greatly reduces sparking between them and the needle, but not the brush-discharge with an alternating potential difference; and is therefore of little practical use. A better method of stopping the brush-discharge than by immersing the whole instrument in oil is much needed.

*Megohm-meters.*—Direct-reading ohm-meters, measuring up to 50 megohms, can now be obtained; but apparatus is also needed

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for enabling the insulation of an electric-light cable to be tested where laid. At present cable is often supplied which, although possessing only a fraction of the specified insulation, is accepted because suitable testing apparatus can be used only in a laboratory.

The Author's cordial thanks are due to Mr. A. Campbell for assistance rendered in the preparation of this note.

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8 JUNE, 1899.

## "Mechanical Traction by Electricity."[1]

By GRANVILLE CARLYLE CUNINGHAM, M. Inst. C.E.

(*Abstract.*)

The saving in mechanical traction by electricity compared with horse traction could be effected, the Author considered, only in the power; and it was therefore upon the construction and economical working of the machinery in the power-house that commercial success depended. The cost of horse traction might be taken as varying from 3½*d.* per car-mile in towns with easy gradients to 5*d.* in hilly towns. With economical engines and boilers, and with heat-saving appliances, electric traction with overhead trolley-wires should cost less than a halfpenny per car-mile in level towns, and but little more than a halfpenny in hilly towns with steep gradients: including the cost of wages, fuel, water, oil, etc., in the power-house, together with maintenance and repairs of the machinery. The cars driven by electricity weighed about 6½ tons empty, and seated twenty-six passengers inside. The adoption was recommended of compound condensing engines running at not more than 70 revolutions per minute, with Lancashire or Galloway boilers, and Green's economizers. With machinery of this kind on the Montreal Electric Street Railway, and with coal at 9*s.* per ton, the cost of producing the current had been a little under a farthing per kilo-watt per hour, and the cost per car-mile less than a halfpenny in the open months of the year. The consumption of coal had been 3·48 lbs. per kilo-watt per hour, or 2·60 lbs. per E.HP.-hour, during several months; while the average for a whole year had been only 2·75 lbs. per E.HP.-hour.

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[1] *The Engineer*, vol. lxxxvii. p. 611; *Engineering*, vol. lxvii. pp. 768 and 796; *The Electrician*, vol. xliii. p. 305; *The Electrical Review*, vol. xliv. pp. 1000 and 1016; *The Electrical Engineer*, vol. xxiii. p. 725.

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There were six 800-HP. engines, and the daily output of current averaged 43,000 units. Similar results had recently been obtained also on the Birmingham small cable tramway, which had previously had a pair of single-cylinder engines running at 53 revolutions per minute and giving 287 HP. as a maximum, with Galloway boilers but no special heat-saving appliances. By the addition of a pair of superposed compound engines of 400 HP., running at the same speed, with condensing water from a well in conjunction with a tank and cooling tower, and by the introduction of Green's economizers, the fuel consumption had been reduced from 8·9 lbs. to 4·7 lbs. per car-mile, or to about 3 lbs. per HP.-hour. The whole cost of working a large electric tramway should be under fivepence per car-mile, which result could be obtained only where the cost of the current at the generating station was cut down to a minimum by the use of engines and boilers that would do their work with a low consumption of fuel.

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## "Economical Transmission and Distribution of Electricity from a Distance."[1]

By Horace Field Parshall, M. Inst. C.E.

(*Abstract.*)

In the economical generation of electricity, so far as the electrical conditions were concerned, it was stated by the Author that the difference was but small between continuous-current, alternating-current, and multiphase generators, in respect of efficiency, cost, and maintenance. In multiphase transmission, intensifying or step-up transformers might be found commercially more satisfactory than generators working at a high pressure.

Economical transmission, so far as concerned the cost of conductors and the efficiency, resulted directly from increasing the voltage in overhead lines. For underground cables 20,000 volts might be taken as the present safe limit.

Economical distribution was determined by the conditions to be maintained in the consumers' circuit. Whether continuous or alternating currents were preferable, or a combination of both,

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[1] *The Engineer*, vol. lxxxvii. p. 612; *Engineering*, vol. lxvii. pp. 769 and 796; *The Electrical Review*, vol. xliv. pp. 966 and 1014; *The Electrical Engineer*, vol. xxiii. p. 727.

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only a small voltage drop could be permitted either for electric lighting or in earth returns for electric traction. A number of small electric sub-stations were commercially more economical than the same number of complete generating stations; they also occupied less space, and could be built free from objectionable vibration and noise. Though they involved lower efficiency in transformation, higher first cost, and heavier charges for attendance, a saving was effected both in feeders and in distributors, and feeder losses were smaller.

The single-phase motor had not been a success; where single-phase transmission had been adopted, arrangements were being generally made for supplying continuous current for power. Multiphase transmission with rotary converters and continuous-current distribution was now looked to for supplying large power over an extensive area. Three-phase transmission required only three-quarters the weight of copper necessary for two-phase currents; and with rotary converters the transformers might be connected for six-phase transformation instead of three-phase, with advantage in practical working. Early difficulties with the rotary converter had been largely overcome by more careful design both in the converter itself, and also in the prime mover, in which the production of constant angular velocity was requisite. Besides the multiphase currents already in use in Dublin and Middlesbrough, multiphase generation was now in progress of adoption for the Central London Railway, the London United Tramways, and the Glasgow and Metropolitan.

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# OBITUARY.

HENRY WOLLASTON BLAKE, born at 25 Portland Place, London, on the 3rd March, 1815, was the youngest son of Mr. William Blake, of Danesbury, Herts, and was named after one of his godfathers, the well-known Dr. Wollaston. He was educated at a preparatory school near Hatfield, and subsequently at Eton, where already he showed a taste for mechanics. On leaving Eton he joined his parents at Prague, and travelled with them in Italy, Germany and France, until October, 1833, when he entered Trinity College, Cambridge. In 1837 he graduated M.A., coming out fifteenth in a list of 52 Wranglers, although, as seven names above his were bracketed, he practically ranked much higher. In order to learn business habits he was placed in the office of Mr. Thompson Hankey, then Governor of the Bank of England, and in the following year he accompanied an agent of the Bank to America, to aid in collecting a large number of protested bills, and held slaves as security. For eighteen months he was constantly employed in travelling through America to collect the various securities, and on his return, had it not been for a fortunate incident which caused him to change steamers, he would have sailed for England on the ill-fated "President," which foundered with all on board.

Soon after Mr. Blake's return to England he became a member of the firm of Boulton and Watt (now James Watt and Co.), of the Soho Foundry, Birmingham. His commercial knowledge, ability, and energy were of great value to the firm, of which he became the head. In that capacity he carried out work in connection with many important undertakings, among which may be mentioned waterworks in Italy, Turkey, Siam, Japan, Straits Settlements, Hong-Kong, and other places; furnished pumping-engines to some of the London Water Companies, to the Metropolitan Board of Works for the drainage of the Metropolis, to the Royal Dockyards, and the London Docks; and supplied machinery for the principal London breweries, for the drainage of the Fens, and engines for many of the ships of the Royal Navy and Mercantile marine, for the Dublin mailboats, for the South Devon Atmospheric Railway, and for the "Great Eastern" steamship, which he accompanied on her trial trips. The firm also supplied machinery to the Royal Mint, as well as to the Mints at Bombay, Calcutta,

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Constantinople, St. Petersburg, and in Japan, Mexico and Chili. Bronze money for Japan and Siam was coined at Soho. Mr. Blake patented inventions for coining machinery, and in 1859 a large mint was erected at Soho from which 2,000 tons of the new bronze coinage for the United Kingdom were issued. Subsequently he was selected to give evidence against the proposed scheme for moving the Royal Mint from its present site to the Thames Embankment.

Mr. Blake was an original Member of the Institution of Mechanical Engineers. In 1843 he was elected to the Smeatonian Society, of which he was the "father" at the time of his death. He was also for fifty-five years a Fellow of the Royal Society and a member of the Athenæum Club, and, since 1872, of the Royal Societies' Club. Taking a great interest in the science of astronomy he accompanied, as recently as 1896, the Expedition to view the total eclipse at Vadsö, and was requested to publish his observations of the variations of temperature during the eclipse. He was a Fellow of the Royal Astronomical Society and of the Royal Geographical Society, and a Member of the Royal Institution and of the British Association, of the Mechanical Engineering Section, of which he occasionally acted as President. For forty-six years he was one of Her Majesty's Lieutenants of the City of London and a Director of the Bank of England. In 1861 he went to Russia in connection with the Varna-Rustchuk Railway between the Danube and the Black Sea, of which line he was Chairman for many years, and in 1888 he was instrumental in carrying through the negotiations for its purchase by the Bulgarian Government. He was for some time a Director of the Grand Trunk Railway of Canada, and from 1842 of the London and North Western Railway. As an engineer he was placed on the Locomotive Committee of the latter line and was able to render valuable service in connection with the company's works at Wolverhampton and at Crewe. He was also a Director of the Great Indian Peninsula and the Indian Midland Railways, and of several other companies.

Mr. Blake died at his town house, 8 Devonshire Place, on the 27th June, 1899, after a few days' illness from pneumonia, in his eighty-fifth year. He was twice married; first to Charlotte, daughter of Mr. John Walbanke Childers, of Cantley, Yorks, by whom he leaves two sons, and, secondly, to Edith, daughter of the Rev. Prebendary Hawkshaw, of Weston-under-Penyard, Herefordshire. He was elected an Associate of the Institution on the 24th June, 1845, and was transferred to the class of Members on the 14th January, 1879.

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WILLIAM FOGGIN, born on the 19th January, 1850, served an apprenticeship of four years with the late Mr. S. B. Coxon, Mining Engineer, and in 1876 obtained a first-class certificate of competency as Manager under the Coal Mines Regulation Act. Between 1876 and 1879 he was Assistant Manager under Mr. Coxon of the Penshaw Colliery, the ventilating arrangements of which he re-organized, superseding the furnace by mechanical means. From 1879 to 1894 he was in charge of the North Biddick Colliery, where he carried out various improvements in the pumping, winding and screening plant, and constructed a branch railway with sidings, which enabled the daily output to be increased from 170 to 600 tons. In 1885 Mr. Foggin succeeded Mr. Coxon as Mining Agent to the late Sir George Elliot, Bart., for whom he inspected and reported on iron-ore deposits in co. Antrim, colliery properties in South Wales and in Nova Scotia, and petroleum properties in Pennsylvania, Ontario and Galicia.

Since 1894 Mr. Foggin practised on his own account as a Consulting Mining Engineer, and in that capacity he was retained to advise the executors of Sir George Elliot as to various mining properties, including the North Staffordshire Collieries. He also inspected and reported on the iron-ore mines at Gellivara in Sweden.

Mr. Foggin died at Newcastle-on-Tyne on the 2nd September, 1898. He was elected a Member of the Institution on the 5th May, 1896.

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HENRY MAUDSLAY, who died in Westminster on the 18th July, 1899, was the eldest son of the late Mr. Thomas Henry Maudslay. After serving a pupilage in the works of Messrs. Maudslay, Sons and Field, he became, first, an assistant to and, subsequently, a member of that well-known firm, in which capacity he was engaged in the construction and erection of steam-engines and general machinery both in England and on the Continent. During that period of his life, in recognition of services rendered to the Portuguese Government, he was created a Chevalier of the Order of Christ. On retiring from the firm, Mr. Maudslay spent a considerable time in Palestine, and carried out at his own expense some important excavations in Jerusalem, rendering in this way much assistance to the Palestine Exploration Fund. He was an enthusiastic Freemason and a member of the Vitruvian, No. 87, Lodge, which met in Lambeth and was composed largely of men from the works of Maudslay, Sons and Field. In 1864 he became Junior Grand Deacon in Grand Lodge and Grand Sword Bearer in Grand Chapter of Royal Arch Masons.

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Mr. Maudslay was a Past Master of the Ironmongers' Company, a Governor of Christ's Hospital, and on the governing committees of many hospitals and benevolent institutions.

He was elected a Member of the Institution on the 6th March, 1849.

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ROBERT REYNOLDS [1] was born on the 15th November, 1833, at Boston, Lincolnshire, where his father, besides other occupations, held the appointment of Surveyor to the Corporation, amongst his duties being that of the conservation of the tidal portion of the river Witham. The subject of this notice, after receiving a sound practical training in engineering, surveying, and field work, was sent to London, and placed on probation with Mr. Freebody, an engineer who was formerly connected with Sir John Rennie. He remained with Mr. Freebody for about six months, during which time he accompanied that gentleman to France to examine and report on a project for the drainage and reclamation of a large lake near Nantes in Brittany, and afterwards assisted in the preparation of plans, sections and estimates for a railway project in the South of England, the bill for which, however, failed to pass in Parliament.

After other work of a miscellaneous description with Mr. Freebody, Mr. Reynolds, wishing to widen his knowledge of engineering subjects and obtain some insight into the practice of mechanical engineering, left that gentleman, and became articled in 1852 for three years as a pupil to the late Mr. Richard Peacock, at that time Locomotive Superintendent of the Manchester, Sheffield and Lincolnshire Railway. By the time he had served about halfway through his indentures, Mr. Peacock entered into partnership with the late Mr. Charles Beyer, founding the firm of Beyer, Peacock & Co., and Mr. Reynolds served the remainder of his term with the new firm, continuing with it until about three months after the expiration of his indentures. An opening then occurred in the drawing office of Messrs. E. B. Wilson & Co., Railway Foundry, Leeds, owing to the despatch by that firm of Mr. Godfrey Mann to Balaclava with locomotive engines for working the Balaclava Railway, constructed to assist in the siege operations against Sebastopol during the Crimean War. Mr. Reynolds secured the position rendered vacant by Mr. Mann's departure, and remained at the Railway Foundry until nearly the

[1] This Notice is, with slight exception, autobiographical.

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close of the year 1857, when having obtained an introduction to the late Mr. Charles Blacker Vignoles, Past-President, he was engaged by that gentleman, as an Assistant Engineer, to proceed to Spain for the surveys and construction of the Tudela and Bilbao Railway to traverse the Cantabrian Pyrenees. Mr. Reynolds arrived in Bilbao on New Year's Day, 1858, and remained on Mr. Vignoles' staff until September, 1862—having been for the last three years in charge of the construction of a heavy subdivision on the summit section—when his work being completed he returned to England.

Early in 1863 Mr. W. F. Faviell, who had contracted with the Colonial Government of Ceylon to construct a railway from Colombo to Kandy, engaged as one of his staff Mr. Reynolds, who arrived in Ceylon in March of that year, and was appointed to the charge of the construction of the entire length of railway of about 74 miles. A few months later urgent private affairs calling Mr. Faviell to England, he appointed Mr. Reynolds as his representative to the Government of Ceylon, which position Mr. Reynolds retained until Mr. Faviell's return, after an absence of about half a year, when Mr. Reynolds resumed his former position as Chief Agent. In September, 1866, by which time the greater portion of the railway had been completed, and nearly half of it was ready for opening for traffic, the health of Mr. Reynolds had become so impaired, by frequent and severe attacks of fever, as to render him unfit for duty, and it became necessary for him to return to England.

In March, 1867, Mr. Faviell, writing from Ceylon, invited Mr. Reynolds to return and resume his former position, take charge of the maintenance of the line when finally completed, and act as his representative in tendering for the construction of such extensions as the Government might propose. Mr. Reynolds' medical adviser in London was so strongly opposed to his early return to the tropics that he felt reluctantly compelled to decline Mr. Faviell's invitation, and preferred to seek further restoration to health by travel in Continental Europe.

In October, 1868, Mr. Reynolds entered the Public Works Department of the Government of India as a Fourth-Grade Executive Engineer, under agreement with the Secretary of State for a term of years. He was posted to the local government of Hyderabad under the Resident, who sent him into Berar, to examine the province and report upon the feasibility, or otherwise, of establishing irrigation works from supplies of water in the rivers whose flow almost ceased in the hot weather. Upon the completion of

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his report Mr. Reynolds was recalled to Hyderabad to commence the survey of H.H. the Nizam's State Railway, about 120 miles in length, to be made from the city of Hyderabad to a junction at Wadi with the Great Indian Peninsula Railway. He surveyed the greater portion of the route, the remainder being undertaken by other engineers, and finally prepared the plans for and constructed one division of 36 miles in length, after which he was transferred, with the rank of Second-Grade Executive Engineer, to the Northern Bengal State Railway, where he completed the construction of a division of about 57 miles in length. In 1877 he returned to England on furlough, having suffered severely for nearly three years from chronic dysentery. A stay of about twenty months in Europe, during which time he underwent a surgical operation, restored him to comparative health, and he returned to his post on the Northern Bengal State Railway in the early part of 1879. His health again suffered, and when the Government of India, in the course of that year, decided to reduce its engineering establishment, and offered, as an inducement to retire, a pension and bonus to those who, like Mr. Reynolds, had been engaged by the Secretary of State for a limited period, he decided to send in his resignation.

Before leaving the country he accepted a temporary appointment from the Government of India to assist in the survey of a line, to be made by the West of India Portuguese Railway Company over the Western Ghauts, from a point on the coast near Goa, to join the Southern Mahratta State Railway system. The surveys were commenced in January, 1880, and the outdoor work was completed before the breaking of the south-west monsoon. Mr. Reynolds found, in his enfeebled state of health, the work of climbing about the Ghauts so arduous and exhausting that he was confirmed in his opinion that he was no longer fit for active outdoor work in India, and left Bombay in July, 1880, for England, where he took a long rest of about three years, during which period his health slowly recovered.

In September, 1883, a chance meeting with Mr. Richard Peacock, of the firm of Beyer, Peacock & Co., led to his being engaged by that gentleman as technical correspondent and personal assistant to Mr. H. L. Lange, chief of the firm's engineering staff. He held that position until January, 1889, when his health again gave way, and he was obliged to absent himself from work for about seven months, at the expiration of which period he returned to the firm under a modification of his former duties. In October, 1896, Mr. Reynolds was attacked by para-

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lysis, which gradually incapacitated him from work. His death took place at Leamington on the 13th July, 1899.

Mr. Reynolds was elected an Associate of the Institution on the 7th April, 1868, and was transferred to the class of Members on the 3rd December, 1878.

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HENRY SIMON was born in Brieg, Silesia, on the 7th June, 1835. His father was Landsgerichtsrath, and was an active business man. His mother was a highly gifted woman who became widely known as an authoress of some distinction. The father of Henry Simon was, too, a director of one of the first German Railways, and as the son passed much of his early youth in and upon works of the railway, his natural inclination to the study of mechanics was aided by the opportunities thus afforded of acquaintance with practical details. It was, however, by his uncle, Heinrich Simon, who took a leading part in the revolution of 1848, that young Henry Simon was largely influenced. Heinrich Simon was a leading member of the Prussian Parliament at that time, and a strong upholder of democratic principles. The robust mind of his nephew accepted teaching which was enforced by a view of the condition of the country, and Henry Simon was always a firm and consistent supporter of the development of the democratic ideal. In consequence of the revolution Heinrich Simon was compelled to leave Brieg, and he was followed by his nephew. The family left Germany for Switzerland, and settled for a time at Zürich, where Henry Simon attended the Cantonal Public School. At the age of 19 he entered the University of Breslau, but subsequently returned to Switzerland and studied engineering at the Federal Technical College, Zurich, obtaining the engineering degree at this college in 1859. He then left Switzerland and went to Berlin to undertake military service, first in the artillery and afterwards in the Guards. His term of military service ended, he entered, as a draughtsman, the establishment of Messrs. Röhrig and König, of Magdeburg, manufacturers of water-motors, turbines, and sugar-works plants. In 1860 he came to England, and was appointed superintendent and resident engineer for railway contracts in Russia by Messrs. Jametel, of Manchester. He spent the greater portion of 1861–62 in Russia on the Railway between Warsaw and Wilna, superintending the execution of various works for a distance of about 300 miles. By naturalisation he became soon afterwards a

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British subject. During 1863–4, his various business journeys were in Italy and France, and on coming again to England he established himself as a consulting engineer in Manchester. He passed nearly the whole of 1867 in Paris in connection with the English section of the International Exhibition there, becoming a life member of the Society of Civil Engineers of France.

Mr. Simon's mechanical genius and shrewd business capacity early made him alive to the defects of the old process of flour milling and the advantages and possibilities of the roller-milling system, by which the production of flour has been improved, cheapened and increased, and which has now been adopted in nearly all civilised countries. In the session of 1881–2 Mr. Simon read a Paper before this Institution describing the new processes by which he proposed to remodel this industry.[1] Among the earliest important works in connection with the roller flour-milling system was the fitting up of an entire plant for Messrs. F. A. Frost and Sons, of Chester, in the year 1881. This was one of the earliest examples in England of a complete adaptation of the roller-milling principle to an automatic flour-mill.

Mr. Simon was largely instrumental in promoting the introduction of the Chaudron system of shaft-sinking through water-bearing strata, of the Lehmann hot-air engine, of the Galland system of pneumatic malting, and—in conjunction with Mr. Carvès—of improved Carvès coke ovens, now well known as the "Simon-Carvès by-product coke ovens." He pointed out the two-fold loss entailed in the use of the old coke ovens, viz., the loss of ammonia and tar by-products, and the loss in vegetation destroyed over tracts of land laid waste by the sulphurous smoke poured from the ordinary bee-hive ovens. He was able to show that by the use of the Carvès oven not only are vegetation and tree life spared, but ammonia is produced as sulphate, to play a useful part as manure; that gas is obtained to serve as fuel, and tar products condensed and stored in proper receptacles, instead of forming a nuisance in being burnt and distributed abroad as smoke and soot. Lastly, an excellent coke for the blast furnace is obtained. It was at the extensive collieries of Messrs. Pease and Partners, in Durham, that this useful invention was first applied on a large scale.

Mr. Simon was a Member of the Institution of Mechanical Engineers, the Iron and Steel Institute, and the Society of Engineers and Architects of Austria, and a Fellow of the Royal Geographical Society and the Society of Arts. He devoted him-

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 191.

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self with peculiar energy to the work which lay nearest, and matters which many men sometimes find a task, he delighted to use as a means of recreation. He would, for instance, turn from the abtruse pursuit of the development of a mechanical appliance to the conduct of some scheme—like that at Ancoats—for the betterment of the more humble classes, or to the furtherance of those studies at Owens, the perfection of which, he profoundly believed, would help to maintain his adopted country in the foremost rank of industrial nations. As a work of love he designed the furnace for the Manchester Crematorium, a similar type to which has since been adopted by the Municipal Council of Shanghai, and also in the Crematorium now being built by the local authorities at Hull.

But the concentration of mind and unintermittent toil involved in the conduct of two or, indeed, three branches of industry—one of pure engineering and the others of chemical manufacture—must have meant a continual and heavy strain of nervous energy and mental power. Latterly, Henry Simon was frequently out of health. His was one of the acute and active minds which must perforce fret "within their earthly tenement," and he might no doubt have lived longer had it been possible for him to act with less constant energy.

Mr. Simon took a full share of the duties of a citizen in the country of his adoption, and won high esteem in Manchester by the warm interest he manifested in local affairs, and the time and help he gave to various local institutions. Among these may be mentioned the Manchester Labourers' Dwellings Company, of which he was the first Chairman. He was a Member of the Council of the Royal Manchester College of Music, and one of the Directors of the "Manchester Gentlemen's Concerts." His name was familiar in musical circles, also, by reason of his connection with the management of the Hallé concerts, in conjunction with Mr. Forsyth and Mr. Behrens. Recently Mr. Simon was one of the originators of the Manchester Pure Milk Supply Company, of the Board of which he was a member. This Company, like most of the various institutions with which Mr. Simon actively associated himself in Manchester, was founded for the public benefit, and not with the idea of private gain. Whilst he was one of the most busy of men, he was at the same time essentially modest, and his work in the cause of education, which will be greatly missed in Manchester, was carried out in so quiet and retired a manner that possibly he was unknown to many of those who have cause to thank the ardour of his zeal. His death took place at Manchester on the

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22nd July, 1899. In 1895 he endowed the Henry Simon Professorship of German Literature at Owens College, and he was a munificent contributor to the fund for the establishment of the new laboratory at Owens.

Mr. Simon was elected a Member of the Institution on the 6th December, 1887.

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CHARLES EDWARD GOODFELLOW, born on the 11th November, 1855, obtained part of his early education at the School of Art, South Kensington, where he gained gold, silver, and bronze medals for designing in metals. In 1877 he became a pupil of the late Mr. Henry Wakefield, with whom he subsequently remained as chief assistant during the whole of his professional career. Mr. Wakefield was Inspecting Engineer for constructional and general works to the Crown Agents for the Colonies, and Mr. Goodfellow assisted him in designing and in superintending the construction in England of numerous iron bridges, lighthouses, dredging-vessels, marine engines and dredging machinery for Bermuda, the Cape of Good Hope, Ceylon, Natal, and other Colonies, and also in the inspection of railway materials for several colonial lines.

Mr. Goodfellow died at his residence at West Dulwich on the 15th May, 1899, in the forty-fourth year of his age, having survived Mr. Wakefield only a few weeks. He was elected an Associate Member of the Institution on the 1st April, 1884.

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GRIFFITH ROBERTS, born on the 6th September, 1868, was articled in 1884 for five years to his father, Mr. Thomas Roberts, of Portmadoc, whom he assisted in carrying out waterworks, sewerage, street improvements and sea defences. Since January, 1891, he designed and carried out, in partnership with his father, sewage-disposal works at Festiniog, street improvements and the development of the South Beach at Pwllheli, an extension of Barmouth outfall sewer to 10 feet below low-water mark, underground surveys and direction of new workings at the Clogau Gold Mine, the Bodlyn Waterworks, and sea-walls and promenade at Criccieth.

Mr. Griffith Roberts died on the 7th March, 1899, after a long and painful illness, at the early age of 30. He was elected an Associate Member of the Institution on the 6th March, 1894.

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JOSIAS EDWARD DE VILLIERS was born in Stellenbosch, Cape Colony, and at an early age, in 1862, was admitted, by examination, a Government Surveyor of the Cape Colony. This admission was subsequently extended, by the action of the respective Governments, to the Orange Free State, Griqualand West and the Transvaal. In 1862 he settled in the Orange Free State, where he practised for sixteen years, after which he went to Johannesburg and, soon acquiring considerable wealth there, retired from the profession. Mr. de Villiers was for many years a member of the Free State Volksraad, and was much esteemed and respected. Shortly after the discovery of the Kimberley Diamond Mines a dispute arose as to the boundary line between Griqualand West and the Orange Free State. Mr. de Villiers was appointed by the Free State Government to determine the disputed boundary line, and, together with Major-General Sir Charles Warren, R.E., he carried out the trigonometrical survey for that purpose. The boundary line thus fixed was approved and accepted by the British and Free State Governments, and Mr. de Villiers received the thanks of Lord Carnarvon, on behalf of the British Government, and a vote of thanks from the Free State Government, for the important and valuable service he had rendered. In 1881 and 1882 he located and made a detailed survey of a line of railway between the Orange River Bridge, near Colesberg in the Cape Colony, and Bloemfontein, the chief town of the Orange Free State.

Mr. de Villiers settled at Sea Point to enjoy a life of cultivated leisure. His principal hobby was astronomy, and latterly he spent a large sum of money in erecting in his grounds a new observatory, fitted with the best and latest appliances. He also had a taste for art, and was a most pleasant companion and one of the most social of men. He was killed in a railway accident in August, 1898.

Mr. de Villiers was elected an Associate Member of the Institution on the 6th December, 1887.

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The following death has also been made known since the 31st July, 1899:—

*Honorary Member.*

Sir Edward Frankland, K.C.B., M.D., D.C.L. (Oxon.), LL.D. (Edin.), F.R.S.; *died* 9 August, 1899.

Information as to the career and characteristics of the above is solicited in aid of the preparation of an Obituary Notice.—Sec. Inst. C.E., 31 August, 1899.

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## Sect. III.

## ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

### *Tests of Certain Native Woods in the Argentine Republic.*

Jorge Duclout.

(La Ingenieria, 1898, p. 177.)

This Paper describes a very complete series of tests upon certain native woods known in the Argentine Republic as the "quebracho," "urunday" and "curupay," and as the beech of Tierra del Fuego. The density of the specimens, the relative duration, and the microscopical structure, were all examined before bending stresses were applied. The density was obtained from sixty-six specimens from Rosario and Riachuelo. In order to compare the relative duration of the three woods, portions were taken from the piles in the jetties at Riachuelo which were built in 1874, and details are also given from other places, with the result that the curupay is shown to last double as long as the quebracho or urunday. The Author reviews the results of torsion tests made by other Argentine engineers and finds considerable want of agreement, so he decided to make new tests and describes the apparatus used; the test pieces were 10 millimetres square in section, and the results are given in Tables and also shown graphically.

Microphotography was also employed, and in the original Paper the structure of the specimens is well illustrated.

E. R. D.

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### *The Arched Beam.* A. Francke.

(Zeitschrift für Bauwesen, 1899, p. 309.)

This Paper treats of the curved beam loaded in any manner in its own plane and subject to various terminal conditions.

The Author derives the following equation as being fundamental for the circularly curved beam:—

$$\frac{E J}{r^4}\left\{\frac{d^3z}{dw^3}+\frac{d^5z}{dw^5}\right\}=t+\frac{du}{dw},$$

$z$ being measured perpendicular to the axis of the beam, $t$ and $u$



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are the tangential and normal components of the external applied forces, and $w$ is the angle subtended at the centre of the circle.

The first particular case is that of the circular fixed arch with concentrated loads, and the solution is given in the form of a group of three simultaneous equations involving as unknowns the terminal bending moment and the longitudinal and shearing forces. This solution is extended to meet the case of the beam in the form of a complete circle.

The next case treated is that of the arch loaded with its own weight, but the Author does not carry the solution so far as in the first case.

Explicit formulas are given for the deflection, bending moment and longitudinal and shearing forces at any point of a semicircular arch with springings at the same level and loaded with its own weight.

Other three cases dealt with resemble as to conditions those of a tunnel arch and an arch carrying a road on a steep gradient.

The Author finally discusses the necessary variations in the solutions when there is discontinuity in the loading, the section of the beam, or in the deflected central axis, this last due to the existence of hinges; also when the moment of inertia varies continuously.

The Paper is somewhat extensive, and almost purely mathematical in character.

W. B.

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## *Simple Method of Calculating Continuous Girders.*

J. JONGEBLOED.

(Centralblatt der Bauverwaltung, 1899, p. 267.)

Starting from equations expressing the vertical displacement of the girder at each point of support in terms of the external loads and the reactions at the other piers, and introducing Maxwell's theory of the reciprocity of displacements, the Author works out a simple method whereby the reactions at the points of support of a continuous girder under any distribution of loading can be obtained by ordinary calculation.

Numerical worked-out examples illustrating the new method are given at the end of the Paper.

W. B.

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## *Dynamics of a Framed Girder.* H. REISSNER.

(Zeitschrift für Bauwesen, 1899, p. 477.)

In this Paper is investigated the problem of the vibration of a framework caused by an instantaneous load; and, proceeding from the equation of energy, the Author arrives at the following expression for the time of a complete vibration:—

$$\tau = 2\pi \sqrt{\frac{m\,\delta_1^2 + \Sigma m_s \left(\delta_{1s}^2 + \frac{s^2\,\delta_{\phi 1}^2}{12}\right) + \Sigma m_l\,\delta_{1l}^2}{\delta_{1y}}},$$

where $m$ is the mass of the applied load.

$m_s$ is the mass of any bar of the framework.

$m_l$ is the mass of permanent load other than $m_s$.

$\delta_{1s}$ the displacement of the centre of gravity of a bar produced by the application of a load R = 1 at the point $n$ where the external load is applied.

$\delta_{1l}$ the displacement of $m_l$ produced by the load above mentioned.

$\delta_{\phi 1}$ the angular displacement of a bar produced by the load as above.

$\delta_1$ the displacement of the point $n$ produced by the load as above.

$\delta_{1y}$ the vertical component of $\delta_1$.

The Author shows by a detailed analysis that the amplitude of vibration of a heavy framework in consequence of a suddenly applied load is double the statical deflection due to the same load.

If the mass of the framework may be neglected in comparison with that of the applied weight, and if the horizontal displacement of the point of application of the load be disregarded, the framework swings as a simple pendulum of a length equal to the statical deflection.

The Author also investigates the effect on a framework of a periodically recurring force such as the unbalanced centrifugal force of the mechanism of a locomotive, that due to a train of wheels passing over a rail joint, etc., and arrives at an expression for the displacement from the position of equilibrium, which shows that the forced vibrations are made up of a free vibration and one following the period of the applied force. Further, if the period of the force is equal to that of a free vibration and there is no damping, the amplitude becomes infinitely great.

It has often been asserted that the period of the force should not be any multiple of the time of a free vibration, but, from the expression obtained, it is evident that for this case the amplitude does not increase very much; and besides, that a force whose

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period is greater than that of a free vibration causes greater disturbance than a more rapidly alternating force.

As regards the damping of girder vibrations, the Author shows that riveted connections and redundant bars are advantageous in that they tend to decrease the kinetic energy of vibrations.

In all cases where amplification of the vibrations is to be expected from regularly recurring forces, the framework should be so constructed that the longest period of a free vibration should not approach that of the force.

The Author hopes to continue his investigations experimentally.

W. B.

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## *Railway Swing-Bridge over the Kaiser William Canal at Taterpfahl.* FÜLSCHER.

(Zeitschrift für Bauwesen, 1899, p. 445.)

This is a single-line bridge similar in general design and arrangements to the other swing-bridges over the canal.[1] The wind forces had to be provided for in a different manner, however, owing to its being a "through" bridge.

The cross girders rest on the bottom flanges and the main girders are made deep enough to allow of a wind bracing girder in the plane of the top flanges, as well as one at the level of the bottom flanges. The top wind-girder transmits the wind force on to the bottom wind-girder, and so to the abutments and pier by means of three stiff frames, one at each end and another in the centre of the swinging portion. Each of these stiff frames is composed of a cross girder, two uprights, and a small lattice girder between the top main booms, and is designed to be of such a strength as to relieve all the intermediate verticals from any necessity for undergoing transverse stress on account of wind pressure.

The lifting cylinder on the central pier being of necessity much below the centre of gravity of the whole superstructure, some arrangement was required to prevent the swing span from being blown over when raised on the pivot.

The special arrangement provided consists of a framework somewhat resembling a very short one-sided floating graving dock, the bridge taking the place of the ship. This rests on rollers and turns with the bridge, preventing its toppling over, but at the same time allowing of its moving vertically upwards or downwards.

W. B.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 469.

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## *Pontoon Turning-Bridge over the Kaiser William Canal at Holtenau.* FÜLSCHER.

(Zeitschrift für Bauwesen, 1899, p. 451.)

This pontoon-bridge, which carries a 15-foot roadway and two 2-foot 6-inch footpaths across the canal, consists of two main or turning pontoons meeting in the centre of the canal, two bearing pontoons situated at the shore ends of and attached to the main pontoons, and two small fixed bridges, one on each side, from the bearing pontoons on to the shore.

The main pontoons are built in four watertight compartments, with ½-inch mild-steel plates and an oak decking, and are designed to sustain a load of 82 lbs. per square foot (a crowd) and a local load of 7½ tons on two wheels.

The bridge is opened by turning the pontoons round their shoreward ends, and this is accomplished by having a chain, one end of which is attached to a mushroom anchor in the bed of the canal and the other to a bollard on the bank, wound round the barrel of a winch which is on a small pontoon alongside of and attached to the main pontoon.

The winch is actuated by a petroleum motor, and as at the commencement of the opening, when the greatest force is required, viz., to start the pontoons, the motor would, if coupled by gearing to the winch, exert its smallest power, it is allowed to come to its full speed first and then it is gradually coupled up to the winch by a friction brake.

The Author considers a pontoon-bridge as an extremely suitable means for crossing ship canals and similar navigable waters when there is not much current, and when the vehicular traffic is not of too heavy a character. The saving in first cost and maintenance is very great, the bridge under discussion, for example, costing only £6,000, while the road swing-bridge at Rendsburg cost £40,000, although of course it is wider than the pontoon-bridge.

W. B.

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## *Road Swing-Bridge over the Kaiser William Canal at Rendsburg.* FÜLSCHER.

(Zeitschrift für Bauwesen, 1899, p. 443.)

This bridge, the total length of which is about 110 metres (360 feet), has a swinging portion 92 metres (300 feet) long, with a clear opening of 50 metres (164 feet).

The carriage-way, formed of oak planking in two layers, is 5·5 metres (18 feet) wide, and the two footpaths are 4 feet 2 inches wide each.

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The weight of the steel superstructure of the swinging portion, together with the timber flooring, is 620 tons.

For dimensioning the various members, the weight of a crowd was taken at 400 kilograms per square metre (82 lbs. per square foot), and that of a vehicle at 20 tons on four wheels.

The lifting and turning machinery is similar to that for the bridges at Osterrönfeld.[1]

The cost of the bridge was 800,000 marks (£40,000), of which £12,000 was for foundations and piers, and £23,500 for the superstructure and machinery.

W. B.

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## *Arched Masonry Dams.* BACHMANN.

(Centralblatt der Bauverwaltung, 1899, p. 10.)

The Author obtains an expression for the deflection at the summit of the dam due to its action as a plain retaining wall. He then supposes the dam to act as an arch subject to a uniform tangential stress throughout its length, and works out the deflection at the centre on this basis. Equating the two values for the deflection thus derived, and applying the result to an actual case with a versine of $\frac{1}{10}$ of the length, the part of the load taken up by the ring or tangential stress comes out as only $\frac{1}{110}$ of the whole load.

The Author concludes generally that giving a dam the greatest curvature practicable does not enable a designer to reckon on the arch form as adding to its strength or stability.

W. B.

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## *Strength of Arched Masonry Dams.* LIECKFELDT.

(Centralblatt der Bauverwaltung, 1899, p. 301.)

The Author first gives two methods of calculating the necessary thickness of a dam built on a curve in plan convex up-stream, so as to utilize the sides of the valley as abutments resisting the thrust due to the action of the dam as an arch. He shows that so far as strength is concerned an arched dam could be constructed of less thickness than a straight one, but he does not recommend this to be carried out in practice, the principal reasons being (1) that the wall would require to deflect so much to bring the arch action into play as to cause horizontal cracks; (2) that the calculations involve too many assumptions. He then gives two other methods of dealing with the problem supposing the dam to

[1] Minutes of Proceedings Inst. C.E., vol. cxxxvii., p. 469.

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have been designed to stand as a straight wall. The first and more exact method is shortly as follows.

Let the top of the dam be the origin of co-ordinates with $x$ axis downwards, $\eta_1$ deflections due to thrust of water and weight of wall, $\eta_2$ deflections due to arch action, $\Sigma$ radial thrust of the arch against the pressure of the water, S tangential thrust of arch, $\lambda$ length of dam, $\eta$ the actual deflection of the dam.

The following equations, etc., are the substance of the Author's process :—

(1) $\eta = \eta_1 - \eta_2$.

(2) $\mathrm{E\,J}\,\frac{d^2\eta_1}{dx^2}$ = moment due to water-pressure and weight of wall.

(3) $\mathrm{E\,J}\,\frac{d^2\eta_2}{dx^2} = \int \Sigma\, dx \cdot x$.

(4) $\Sigma = f(\mathrm{S}) = f(\Delta\lambda) = f(\eta)$.

$\eta_1$ is determined from equation (2). By equation (3) $\Sigma$ is expressed in terms of $\eta_2$, and further by means of equation (1) in terms of $\eta$ and $\eta_1$; but $\eta_1$ is known; that is, finally we have an equation involving $\Sigma$ and $\eta$ alone. But equation (4) also involves the same two unknowns. Hence can be determined the value of $\Sigma$, and consequently the extent to which the stress on the masonry is relieved by the arch action.

This method might be carried through in an actual case, but for the purposes of his Paper the Author gives a second method by which he is enabled to compare the moments resisting the overturning force of the water of the internal forces of the dam when it is regarded simply as a retaining wall, and when it is regarded as an arch. He assumes a value for the deflection at the top of the centre section of the wall of $\frac{1}{2000}$ the breadth of the base, and calculates from this the internal forces brought into play in the two cases. He finds that the action of the dam as an arch is greater (1) with a constant central angle the smaller the span; (2) with a given span the greater the curvature and the higher the wall; (3) the greater the thickness of the dam at the summit. Generally, however, with the usual proportions, the action of a dam as an arch is practically nil, and would only commence in case the whole mass became disintegrated through cracks. But with very high short dams having a fair central rise in proportion to the span, the arch form is a considerable help to the stability of the whole structure. Even with dams of ordinary proportions, however, the Author recommends that they be built on a curve, as that form will tend to prevent the formation of vertical cracks.

W. B.

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## *Clay as Puddle Material.* M. Gary.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1898, p. 331.)

A sewer to be built near Mainz had to be protected from ground water by a clay puddle wall, 20 inches thick. The choice of a suitable clay for the work was a matter of great importance, and three kinds, being selected for experiment, were submitted to the Royal Testing Laboratory. In order to test their imperviousness to water, two disks 3¼ inches diameter and 1¼ inch thick were pressed from each material. One side of each disk was supported on blotting-paper, which in turn rested on a piece of wire gauze, and was then placed in a metal box, to one end of which water under pressure was admitted. A screw gland made a watertight connection around the periphery of the disk, while the water that penetrated through the disk was allowed to drop through the blotting-paper and wire gauze support. The three materials were each found to be quite impervious to water at a pressure of 1½ atmospheres, the pressure being maintained 48 hours. A small amount of water passed through two of the clays, the pressure being 2 atmospheres and the duration of the test 96 hours; one specimen remained absolutely impervious under the same conditions. Experiments were made on the mechanical composition and on the plasticity of the clays. The laboratory tests indicated one of the materials as being more suitable than the others, agreeing with the opinions based on practical experience of the contractors.

A. S.

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## *Defects in the Waterworks Reservoir at Buenos Ayres.*

Carlos Wauters.

(La Ingenieria, 1898, p. 243 *et seq.* Figs.)

The covered reservoir in Buenos Ayres was originally constructed under the supervision of Mr. Gabriel Mestreit, of Liége, Belgium, and it has been found that certain of the columns supporting the roof were cracked, and the defects were first observed in 1893. The reservoir consists of twelve tanks placed upon three superposed floors, with four tanks on each floor; these are supported on the four lateral walls, and also upon 180 pillars by means of beams. Each pillar consists of four cast-iron columns having an external diameter of 16 inches at the base and a thickness of 0·88 inch, and these dimensions decrease towards the top of the building. The four columns are fixed to a hemispherical base, which itself rests in a bowl-shaped casting.

The intention of the engineers, Messrs. Bateman, Parsons, and

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Bateman, appears to have been to obtain free scope for expansion, which is, of course, considerable in tanks having sides 140·8 feet long. There has been no chance of observing whether this result ever took place, as no means of lubrication were provided, and the surfaces soon became rusty, and all movement was therefore prevented. At first a grouting of cement was used between the cast-iron base and the top of the stones forming the foundation, and the Author favours this method, but the English engineers directed the use of sheet-lead, believing it would fill the space better than cement.

The Author calculates the unequal loading of the columns brought about by the packing not filling the space properly. It appears that the bases of several columns cracked when the tanks were first filled, and others have cracked since.

E. R. D.

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*Test of a Mechanical Filter.* EDMUND WESTON.

(Engineering News, New York, 13 July, 1899, p. 29.)

The filter tested was of the Jewell gravity type, and the test was conducted at Providence, R.I. The rate of filtration was 125,000,000 gallons per acre per 24 hours. The test lasted for 110 days, during which the filtered water was pumped into the mains for delivery to customers. Sulphate of alumina was added to the raw water in the form of a coagulant solution, prepared by dissolving one part of sulphate of alumina, containing 22 per cent. of alumina, in twenty parts of filtered water. This was added to the water at the rate of one grain per gallon. The average reduction in impurities during the test was as follows:—Total solids, 6 per cent.; chlorine, 1 per cent.; ferric oxide, 61 per cent.; alumina, 38 per cent.; free ammonia, 29 per cent.; albuminoid ammonia, 63 per cent.; and colour, 83 per cent. There was also an increase in hardness of 20 per cent. The bacteriological results were even more remarkable. The number of bacteria per cubic centimetre were taken before and after filtration; the lowest reduction was 96·56 per cent., the highest 100 per cent., and the average 99·24 per cent. It is supposed that at times the bacteria grow in the filter, and are carried through during the process of filtration, which would produce an apparent diminution in the percentage of reduction.

A. P. H.

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## *The "Wegener" Furnace for Melting House-refuse in Berlin.*

W. HÄNTZSCHEL.

(Gesundheits-Ingenieur, 15 June, 1899, p. 172.)

An account is given of recent experiments conducted in Berlin in melting ashes and house-refuse in special ovens or furnaces on Wegener's system. These trials are being carried on under the control of the municipal authorities. The whole of the rubbish as collected is raised to the top of a three-storey building which has somewhat the appearance of a blast furnace. The hoisting apparatus is electrically driven, and the ash-boxes with their contents are discharged, along with a supply of coal-dust as fuel, into funnel-shaped hoppers, which lead into the furnace proper, situated in the middle storey. The central furnace is supplied with air at a high temperature, and here a species of dry distillation of the refuse takes place in two large inclined rotary drums of wrought-iron. Out of these it is gradually expelled into the melting chamber in the lower part of this storey, where it encounters a hot air-blast, and is mixed with coal-dust. In this chamber combustion takes place at white heat, and all the rubbish is either burned up or is melted into clinker. This clinker or black slag runs off at the hearth of the furnace into the lowest storey. It is pointed out that no artificial air-blast is needed, the draught of the chimney being sufficient to effect complete combustion, and the process which is continuous is conducted without noticeable smoke or smell. It is claimed that the resultant slag, made into blocks, will be useful for purposes of harbour construction, etc., or when reduced to a powder it will, owing to its great hardness, be valuable for cutting and polishing purposes.

G. R. R.

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## *Utilization of Town-Refuse.* Dr. THEODOR KOLLER.

(Annalen für Gewerbe und Bauwesen, 15 June, 1899, p. 252.)

For more than twenty years the subject of the profitable disposal of town-refuse has been under active discussion, and whereas formerly the opinion was expressed that the solution of this problem must be sought for in the separation and utilization of matters of value and of the manurial ingredients, such as rags, paper, metal, bones, etc., from the wholly worthless substances, the rapid growth of large towns has now rendered it necessary to seek out means for the immediate removal of all rubbish, and the question of profit has become a matter of secondary consideration. In England the introduction of so-called "destructors" for burning refuse has made great progress, but this system entails

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an outlay of from 4*d.* per ton to 1*s.* per ton handled. The resultant ashes and clinker find a sale for industrial purposes, and the heat generated in the process can be well utilized for electrical lighting, air-compressing, etc. In Berlin it is estimated that 1,000 tons of rubbish are produced daily, and trials with the destructor-furnaces demonstrated that 60 per cent. of this refuse remained after treatment unconsumed; the process had therefore to be abandoned. An account is given of the so-called Buda Pesth sorting process and of a similar treatment of the Munich refuse at Puchheim, where from sixty truck-loads to eighty truck-loads of ashes, etc., are dealt with daily. Every article of value is sorted by hand as the rubbish is conveyed in front of the work-people on a continuous belt. The worthless residue is used for raising the level of some marshy land in the vicinity. The Author describes also the Wegener process,[1] which aims at the destruction by heat of all organic and combustible substances and the melting of the entire residue at a temperature of 2,000° C. It is estimated that the Berlin refuse treated on this system will yield 2,800 HP. hourly.

G. R. R.

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*Steam Mains for Electric-Supply Stations.* R. SUMMERFIELD.

(Engineering, 10 March, 1899, p. 301.)

The continuity of steam supply in electric-light stations is of paramount importance. Some installations have complete duplicate connections and mains, whilst in most cases the "ring" type, that is, an endless ring into which all the boilers feed, and from which all the engines draw, is considered sufficient. The Author suggests a single main of a sectional area equal to one and a half times what is required for the passage of the steam, and fitted with separate stop valves for each engine and boiler, in addition to those on the engines and boilers themselves. All steam-pipes should be riveted, instead of bolted, except at the stop-valves. The disadvantage of the bolting is that the joints open slightly when cold, admitting water, which rots the packing, and makes the joint leaky. The Author also suggests the use of steam separators, to dry the steam instead of draining the steam-pipes. Steel steam-pipes are largely used now in place of copper ones over 2 inches diameter, the flanges being welded on. Stop-valves are also made of cast steel with phosphor-bronze seats and valves. Expansion should be provided for by large bends, in preference to the usual socket arrangement, which is difficult to keep tight at high pressures. These bends should be laid horizontally to avoid accumulation of water. The pipe should nowhere be fixed rigidly to the building, but should rest on rollers, or be slung from over-

[1] *Ante*, p. 508.

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head girders. The covering of steam-pipes is very important when the pipes are long. There is a loss of 1 HP. for every 31 feet of uncovered 12-inch pipe. Slag wool is perhaps the best lagging material. The usual method is to fix a thin metal covering outside the pipe, leaving an interval of from 2 to 3 inches, into which the wool is packed. An additional advantage of riveting the flanges is that they can be covered up.

A. P. H.

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## *The Adige Electrical Works.*

(Zeitschrift für Elektrotechnik und Maschinenbau, 1899, p. 383.)

In the gorge of the Toll, at the lower end of the Vintschgau, the River Adige falls about 230 feet in a distance of about ¾ mile. This has been utilized for supplying light and power to the towns of Meran and Botzen by building a weir across the head of the rapid and leading the water on the level by an open canal 300 metres long, followed by a tunnel of 535 metres, and then by a series of inclined drifts bored through the rock to two lines of riveted steel pipes, 5½ feet in diameter, which connect with the machinery in the power-house. The effective head is about 69 metres (246 feet), and the capacity of the conduit from 8 cubic metres to 9 cubic metres per second (or from 7,300 HP. to 8,500 HP.). The power-house is arranged for six turbine dynamos of 1,200 HP. each, of which four have been erected and the remaining two are in course of erection. Two of these are employed for lighting and power purposes, and the other two supply current for a calcium carbide works. The motors are partial admission Girard turbines, with horizontal axes carrying the dynamos on the same shaft; the admission is governed automatically by the regulator, and the power developed at 320 revolutions is 1,200 HP. The dynamos are unipolar alternators with stationary armatures, and give 800 kilowatts at 320 revolutions. Those serving the towns have double windings so as to give currents at two different tensions, viz., 3,600 volts for Meran and 10,000 volts for Botzen. For the carbide works the current is kept at 3,000 volts. The high-tension currents are conveyed by bare copper conductors carried on porcelain insulators and tall larch poles, the distance to Meran being 5 kilometres (3·1 miles), and to Botzen 34 kilometres (21 miles). At Gries, outside Botzen, the pressure is reduced to 3,000 volts. In the towns there are numerous transformer stations, partly arranged in advertising pillars and partly in ornamental wooden houses, which bring the current down to 115 volts, at which pressure it is distributed to the consumers. The current is utilized for public and private lighting, about 110 arc and 23,000 glow-lamps being already supplied, and to some extent, about 120 HP. for mills and small machinery. Motors

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below 3 HP. are supplied from the secondary network, but those of larger size are connected with the high tension line by independent transformers. The average charge per glow-light of 16 candle-power is 15*s.* per annum, and for power per year of 2,400 hours £5 per HP. if taken during the daytime only, and twice that sum if taken at any time during the day and night.

H. B.

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*The Projected Legislation on Smoke-Prevention in Berlin.*

W. Hantzschel.

(Gesundheits-Ingenieur, 30 June, 1899, p. 193.)

A commission appointed three years ago by the Prussian Minister for commerce and industry, has recently reported as follows :—"The Commission deems it expedient and practicable to issue regulations, applicable in the first instance only to Berlin, prohibiting on and after the 1st October, 1899, the emission of black, dense and long-continued smoke from fire-places." The Author draws attention in the first instance to the results of similar legislation in other countries. In London, regulations for smoke-prevention, which were first promulgated under the Public Health Act dating from 1891, have been since April, 1898, vigorously enforced by the London County Council, and some recent prosecutions are noticed. In Paris, where almost identical rules have been in operation since October of last year, offenders have been very leniently dealt with and have been allowed time to remedy defects. In Buda Pesth the regulations against smoke have been very strictly enforced, and the complaints arising in Berlin concerning the injury which will be caused to various industries if these new rules are carried out are of the same nature as those formulated in Buda Pesth, and are very marked. The Author asserts that the agitation against smoke is not due to the public so much as to those interested in smoke-preventing appliances or in various kinds of smokeless fuel. The measures which must be taken to abate the nuisance are discussed, and it is asserted that, owing to the great progress which has recently been made in gas-firing, there is reason to hope that all smoke may eventually be abolished.

G. R. R.

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*The "Riché" Wood-Gas Producer.* F. Manaut and L. Roman.

(Mémoires de la Société des Ingénieurs Civils de France, 1899, p. 241.)

The Authors in an historical survey point out that wood-gas is no new product, records of its previous use extending back to the year 1791. Having described the usual type of furnace employed

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for the distillation of wood, an account is given of the various products obtained from same, and of the earlier experiments of Mr. Riché. The "Riché" producer is described, which consists of one or more long cast-iron retorts arranged vertically in a masonry setting, and heated externally by one or more furnaces, which are arranged in a somewhat similar manner to a Siemens hearth. A combustion chamber is built in the centre of the structure, and the hot gases are led to the retorts. A full detailed description is given of the various parts of the apparatus, special attention being directed to the arrangements of the retorts which are closed at the top, the gases being forced to travel downwards and through a water seal at the bottom. The Authors state that the working of the apparatus is as simple as the construction. The operation of charging the retort occupies from 1 minute to 1½ minutes, and the period of distillation varies from 40 minutes to 60 minutes, according to the dryness of the wood. The retorts being all made of the same dimensions, the output of any producer is a multiple of the capacity of one retort, which varies from 7 cubic metres to 10 cubic metres (247 cubic feet to 353 cubic feet) per hour. By forcing the temperature and choosing the wood, Mr. Riché has, in certain cases, obtained as high as 12 cubic metres and even 15 cubic metres (423 cubic feet and 530 cubic feet) per hour. Two curves are given which show the production of gas during the process of distillation. The best woods have been found to be wych elm, oak, chestnut, and beech; and the sizes most suitable are those of about 4 centimetres to 7 centimetres (1½ inches to 2¾ inches) in diameter. All kinds of wood waste have been successfully experimented with, and producers have been made to work on raw petroleum and even street refuse. The Authors describe with sectional drawings some modifications of the "Riché" producers, and more particularly those with twin retorts, of which details are given. These are particularly recommended for the distillation of waste, such as that from saw-mills and repairing shops. The products obtained during distillation may be divided into three classes:—(1) Condensable products; (2) incondensable gas, either combustible or non-combustible; (3) charcoal residue. The quantity of gas and its quality become better as the apparatus gets hotter, but with great heat the gas becomes lighter, and has a less illuminating power. An analysis of the gas obtained from a producer working so as to give the greatest possible quantity of gas is as follows:—

| | |
|---|---|
| $CO_2$ | = 21·33 |
| CO | = 22·00 |
| CH | = 12·47 |
| H | = 44·20 |
| | 100·00 |

Analyses made by Mr. Chavanon show the calorific value of this gas, the amount being 3,028 calorific units to the cubic metre

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(35·3 cubic feet). The average may be taken as 2,900 units to 3,000 units per cubic metre (35·3 cubic feet). Experiments made to test the inflammability show that the maximum is obtained in a mixture containing not more than 51, and not less than 12·75 parts of gas to 49 and 87·25 parts of air. The maximum explosibility was found in a mixture of 32 parts of gas to 68 parts of air. The temperature of the flame is about 2,000°. The applications of the gas are comprised under the heads of heating, lighting, and motive power, many examples of which are given. With incandescent burners a light of forty to fifty candles has been obtained, with a consumption of 200 litres (7 cubic feet) per hour, and in gas-engines a consumption of 807 litres (28½ cubic feet) per HP. per hour. The economy and costs of the system are dealt with, several examples being given. In one instance, an installation supplying gas for 180-HP. engines, the cost per HP. hour worked out at 0·025 franc (0·25*d.*).

In conclusion, the Authors point out the various conditions under which this system works most successfully, special attention being drawn to its value for use in the Colonies, and in other places where wood is abundant.

The Paper is illustrated by 18 Figs. in the text.

H. I. J.

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## *Extension of the Orleans Railway to the Quai D'Orsay.*

A. DA CUNHA.

(La Nature, 22 July, 1899, p. 119.)

Details are given of the works now in progress for this railway extension,[1] illustrated by photographs and plans. Part of the line is already complete. There will be but one intermediate station at the Quai St. Michel, which will only be used for local traffic and for passengers without luggage. Electric traction will be employed throughout, and the change of engines will take place at the Walhubert station. The time occupied in traversing the new railway, which is nearly 2½ miles in length, will be seven minutes. It is intended hereafter to connect the lines of the Orleans and Western Railway Companies by means of a branch railway passing in front of the Chamber of Deputies, and uniting the Quai D'Orsay with the Invalides.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 400.

G. R. R.

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## *The Jungfrau Railway.*

(Archiv für Post und Telegraphie, 1898, p. 573. 2 Figs.)

In the year 1889 there were two projects for underground wire-rope railways, one to be worked by water on the gravity system, and the other by air-pressure; then, in 1890, Locher, the builder of the Pilatus railway, brought forward another scheme with two tunnels and compressed air, but none of these plans was carried forward.

Mr. Guyer-Zeller obtained a concession in the year 1893 to construct an electric railway from the little Scheidegg to the Jungfrau; work began in 1896 and is now nearing completion.

The route of the railway is shown in two plans in the original, and the Scheidegg station is 6,811 feet above sea-level on the Wengeralp railway. For a distance of 1·24 miles the line is open, and the remainder 6·45 miles is in tunnel to the base of the peak of the Jungfrau; the gradient is 25 per cent. At Grindelwaldblick there is a station hewn in the rock, with refreshment-room lighted and heated by electricity; with bedrooms for visitors and living-rooms for the staff. A branch tunnel leads to Mönchjoch, where a hotel will be built. The main line there has a 12 per cent. descent and finally a 25 per cent. ascent. At the end of the railway is a vertical shaft 241 feet high served by a lift, by which visitors are taken to the summit itself, 13,748 feet high. The power for working the line is obtained from two waterfalls which together develop 10,000 HP. Three-phase current at 7,000 volts will be used and transformed down to 500 volts direct current.

E. R. D.

## *Ventilation of the St. Gothard Tunnel.*

(Centralblatt der Bauverwaltung, 1899, p. 310.)

Up to the year 1890 the difference of air-pressure in the two ends of this double-line tunnel (length 9¼ miles) and the resulting through current of air was sufficient to keep the atmosphere pure enough for platelayers to work comfortably in, but after that date the traffic increased so much that it became necessary to resort to artificial ventilation, and in March of 1899 a complete plant on Saccardo's system was set in operation to effect this object.

The installation, which is situated at the north end of the tunnel, consists of a locomotive driving two fans, each 5 metres (16·4 feet) in diameter. These fans compress air into a chamber surrounding the face of the tunnel from whence it issues through an annular aperture and in a southerly direction along the tunnel,

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dragging the mass of air in the body of the tunnel along with it on the same principle as the steam injector.

Since the plant has been in operation the air in the tunnel has been pure and free from smoky smell, and besides facilitating the work of platelaying and inspection it is expected that the permanent way will have a longer life under the new conditions. The cost of the installation, exclusive of the locomotive, was about £7,200.

W. B.

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*Work done in getting up the Speed of Trains.* WITTFELD.

(Centralblatt der Bauverwaltung, 1899, p. 290.)

The design of locomotives for city and suburban traffic where the stations are not far apart depends more upon the work to be done in getting up speed than that in hauling the train at a constant speed.

The tractive force exerted during the time of getting up speed is assumed by the Author to be constant, and he explains how he considers this practical both for steam and electric traction. The resistance of the train is taken to be expressed by the formula

$$L\left[\lambda+\left(\frac{v}{c}\right)^2\right]$$

where L is the weight of locomotive and train together, $\lambda$ and $c$ are constants. Also put $s_o=\frac{c^2}{2g}Z$ = tractive force. If L is in kilograms and $v$ in metres per second, the value for $\lambda$ is $\frac{1}{400}$ and for $c$ 280 metres per second.

From the equation—

$$\frac{dv}{dt}=\frac{Z-\text{Resistance}}{L}g;$$

if $v$ denote the velocity at distance $s$ from starting point and $v_g$ the terminal velocity—

$$v=v_g\sqrt{1-e^{-\frac{s}{s_o}}}$$

$$v_g=c\sqrt{\frac{Z-L\lambda}{L}}.$$

The extra pull required when getting up speed over that necessary when the speed has become uniform and equal to $v$ is—

$$\Delta=L\frac{\left(\frac{v}{c}\right)^2}{1-e^{-\frac{s}{s_o}}}e^{-\frac{s}{s_o}}.$$



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The total time between any two stations distant S apart is

$$\tau = \frac{s_c}{v_g}\left\{\log_e \frac{1+k}{1-k} + \frac{\log_e(1-k^2)}{k}\right\} + \frac{S - s_b}{v_c} + t_b,$$

where $k = \frac{v_c}{v_g}$ and $s_b$ and $t_b$ are the length and time through which the brakes are applied.

Several other formulas and tables are given for the maximum, minimum, and average values of the horse-power, tractive force, etc., at various stages of a journey.

The Author also determines the speed which corresponds to the minimum time and tractive force, and the greatest speed which is attained with the minimum tractive force for a given time in which to complete a journey. No explanation of the origin or defence of the constants used throughout the Paper is given.

The Author intends to show in a future Paper that, for the city and suburban traffic of the Prussian State Railways, electric traction is less suited than steam traction.

W. B.

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## *Locomotive Repairs and Renewals.*

R. PRICE-WILLIAMS, M. Inst. C.E.

(Engineering, 5 May, 1899, p. 595.)

From data supplied by Mr. Webb from 1869 to 1898 as to the cost, weight of materials, and wear and tear of locomotives on the London and North Western Railway, the Author calculates their average life and the total cost of keeping them in an efficient and normal condition during that time. Allowing for the vastly varying life of the different parts, from six months for the brake-blocks to thirty years for the side frames, the Author finds the average life to be about 10·8 years. The total expenditure on locomotives during the above-mentioned period of thirty years was £11,374,734, or £4,897 per locomotive, or £163 5*s.* per locomotive per annum. These figures are almost in exact agreement with Mr. Webb's data supplied in 1869, viz., £4,890 as the total cost of a locomotive throughout its life, or £163 per annum. Having regard to the great changes during the last thirty years in wages paid, decreased cost of material, improved machinery, etc., there is a curious coincidence. Although the number of locomotives has increased by 88 per cent., the total amount expended in wages, their maintenance and renewals, has only increased about 30 per cent., while the wages per engine have actually decreased 30 per cent., which would balance an increase per locomotive for maintenance of as much as 44 per cent. The

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decrease is more striking, as it has taken place during a period of increasing rates of wages, and of large augmentations to the material used per locomotive. Although the cost of material has fallen 60 per cent. during the said period, yet the cost of material per locomotive has fallen only 20 per cent., the discrepancy being accounted for by the larger quantity used. If locomotives now built were similar in size to those used in 1869, the reduction in cost of material per locomotive would be more commensurate with the reduction in the cost of the material itself.

A. P. H.

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## *Electric-Pneumatic Signalling Plant.*

(Engineering, 16 June, 1899, p. 773)

The plant described was supplied to the Great Eastern Railway Company by Messrs. McKenzie & Holland of London and Worcester, and by the Westinghouse Brake Company of King's Cross.

Its object is to actuate signals and points by mechanical means, manual force being reduced to the making of electrical connections.

The motors used are of two kinds, that for working the signals being the simpler in construction. It consists of a single-acting air-cylinder, capable of receiving air under pressure and exhausting it, on one side only, the valve being manipulated by an electro-magnet. Under normal conditions the exhaust valve is opened, and the signal is kept in its ordinary position by a counterweight. To alter the signal, the signalman passes a current through the electro-magnet, which shuts the exhaust and opens the inlet valve, thereby raising the counterweight and moving the signal. To return the signal to its ordinary position the current is cut off.

The motor for working points is more complicated. There are two simple motors as described, but these, instead of operating the points direct, merely operate the valve of a separate double-acting air-cylinder, which works the points direct. The current for the magnets is supplied by accumulators, whilst the air-compressing pumps are driven by hydraulic engines working at 750 lbs. per square inch pressure, the air being compressed up to 75 lbs. per square inch.

A. P. H.

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## *Through Transportation on Common Roads and Street Railways.*

(Engineering News, New York, 15 June, 1899, p. 378.)

Colonel Bonner, of Toledo, Ohio, has devised a convenient means of goods traction in towns, which is especially adapted to the transport of farm produce from outlying districts. An ordinary road wagon, carrying from 3 tons to 7 tons, is mounted upon a special car, fitted with strong running gear and springs. It is made of steel, with recesses to receive the axles of the wagon, which is raised up to the requisite level by an inclined plane at the transfer points. When thus loaded, the car is coupled up to the ordinary electric street tramcar, and taken as near as possible to its final destination, the remainder of the journey being accomplished with the farmer's team of horses. The cars and wagons are made by the Bonner Rail Wagon Company. The system is operated upon the tram mileage system, contracts being authorised by the Town Council between the company and the city and suburban electric railways. This system of transport is efficient, but has been discontinued in Toledo for the present, owing to the excessive mileage rates, and also on account of the lack of traffic. It is considered more suitable for a larger centre. It is stated that a saving of 45 per cent. on the original transport and cartage charges was effected. Another great advantage is that all rebilling and receipting from one hand to another are avoided, since there are no intermediate hands, such as truckmen, warehousemen, etc., for the goods to pass through.

A. P. H.

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## *Transportation of Minerals by Rail.*

J. D. TWINBERROW, Assoc. M. Inst. C.E.

(Engineering, 9 June, 1899, p. 752.)

The United Kingdom has not fully participated with other countries in the increased size of locomotives and carrying power of trucks, the attention of engineers being chiefly directed to standardising and improving the details of construction. The economy resulting from such increased size would be due partly to saving on account of greater carrying capacity, and partly to a saving of power, an increase of only 85 per cent. in power being necessary to haul double the weight. The Author calculates the saving by the introduction of larger locomotives and wagons on the Midland Railway to be as follows: due to the employment of larger wagons with existing locomotives, 14·7 per cent.; due to doubling the hauling power of locomotives, keeping the wagons as at

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present, 31·1 per cent.; due to the combination of more powerful locomotives with larger wagons, 41·2 per cent. The first-mentioned saving of 14·7 per cent. would lead to a reduction in working expenses and maintenance of way. Taking the analysis of traffic between Kettering and London in 1896, the total mineral and goods traffic was 25 million train-miles, of which 14¾ millions were for mineral traffic, costing at 11·68*d.* per train-mile, nearly £718,000. Assuming 3¾ per cent. interest, this represents 2¾ millions, 6 millions, and 8 millions of pounds capital respectively, according to whether large wagons, or large locomotives, or a combination of the two, are used, and the saving effected thereby would justify an expenditure of the above sums of money. An increase in wagon capacity would not necessarily involve an increase in wheel base, as the wagons could be extended farther at each end, and the doors could then be placed outside the axles. A special design of buffer has been devised by the Author's firm to avoid undue resistance on curves.

A. P. H.

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## *The Iron-Ore Mine of Rar el Maden.*

(Stahl und Eisen, 1899, p. 668.)

This mine, which has recently been started, is situated about 5 miles inland from Honaine, a small fishing-boat harbour on the coast of Algeria, between Oran and Nemours, near to the mouth of the Tafua River. The ore is a limonite, containing from 50 per cent. to 52 per cent. of iron, and 5 per cent. to 8 per cent. of manganese, with 4 per cent. to 7 per cent. of insoluble siliceous residue, which occurs in a large compact deposit between limestone and slate about 130 metres long and 50 metres broad. The depth is taken to be about 50 metres, although borings down to 59 metres are still in ore. The working is carried on by open quarrying in a series of terraces, but preparations for deep working have been made by sinking a main hoisting shaft. The ore is conveyed from the mine to the beach by a Pohlig wire ropeway, the first section of about 1½ miles having a rise against the load of 190 metres (from 460 metres to 650 metres), from which point to the sea the distance is about 3½ miles. The widest span between the supports on the line, which have a maximum height of 29 metres, is 700 metres. The carrying capacity is about 20 tons per hour. The loaded buckets are discharged on a pile at the cliff face, whence the ore is carried in buckets along plank-ways to open lighters carrying from 10 tons to 14 tons each, which, when filled, are taken out to the steamers lying in the roadstead and discharged in the same way. In spite of the very primitive character of the arrangements, as much as 2,000 tons can be shipped in 24 hours. The ore is sent to Westphalia *viâ* Rotterdam,

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about 38,000 tons having been exported since the working began in December, 1898, which will be increased to 60,000 tons or 70,000 tons at the end of the first year's working, and will be largely increased when the deep workings are regularly started.

H. B.

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*New Form of Walling-Stage for Pit-Sinking.* De Serres.

(Comptes Rendus mensuels de la Société de l'Industrie Minérale, June, 1899, p. 141.)

This is an arrangement adopted in the sinking of the Flaches pits at the Saint Etienne Collieries, which allows the position of the platform used in laying the brickwork lining of the pit to be changed without the assistance of the engine at the surface. The circular platform, of 3·65 metres diameter for a clear width within the finished brickwork of 3·75 metres, is made with two hinged flaps at the sides; and a notch for the passage of a pipe of 1 metre diameter for ventilating the bottom of the sinking is suspended by chains from four short projecting pieces of rails built into an upper stage of the pit wall about 10 feet above the bearing curb. Each of these suspensions includes a length of 15 metres of chain at the top, followed by a differential pulley block tackle of 15 metres, of Schäfer and Budenberg's construction, with worm wheel and screw driving gear; and a bottom length of 2 metres of chain, the latter being adopted to keep the lower pulley clear of droppings of mortar or other chances of obstruction. Each tackle is guaranteed to carry 2 tons, or eight tons for the four, while the total load is about 36 cwt., made up of 20 cwt. for the platform, and 16 cwt. for 6 men to 8 men and their working tools. The lift of the tackle is 15 metres, so then only one readjustment is necessary in each length of walling, which is fixed at 30 metres. The level of the stage is shifted by four men, one at each tackle, during which operation they are chained together by safety-belts. When the required position is reached the platform is fixed for the time by bolts from the four corners of the central part shot into holes left in the brickwork. By the use of this arrangement a saving of time has been effected, which is estimated by the Author at 10 days in each length of 30 metres of walling, or about 2 months in the 180 metres of the total depth of the sinking. The cost of the suspending blocks and chains is 260 francs (£10 8s.) each, or £42 for the four, while the saving as compared with fixed stages is £70 per 30 metres or £2 8s. per metre.

H. B.

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## *An Underground Pumping-Engine with Corliss Gear.*

S. STEUER.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1899, p. 341.)

At Ettes, near Salgó-Tarján in Hungary, an engine containing several novel features in its design has been erected in a new shaft for draining some coal-workings at a depth of 220 metres below the surface. In order to save breadth in the engine-room, owing to the want of stability in the ground, a tandem compound arrangement has been adopted, the steam- and pump- cylinders being in one line, with a crank axle and fly-wheel worked by a back rod from the pump side placed in a central position between them. By this arrangement the whole of the machinery is contained in an arched chamber 42 metres long and 4 metres broad, all the parts being readily accessible from either side. The leading dimensions are:—

| | | |
|---|---|---|
| High-pressure cylinder . . . . | diameter | 500 millimetres. |
| Low-pressure „ . . . . | „ | 800 „ |
| Differential pump-plunger . . | diameters | 200 „<br>189 „ |
| Length of stroke . . . . . | | 600 „ |
| Air and bottom lift pump . . . . | diameter | 550 „ |
| „ „ „ . . | length of stroke | 300 „ |
| Revolutions per minute . . . . . | | 50 normal.<br>67 maximum. |
| Water lifted . . . . . | | 1,500 normal.<br>2,000 maximum. |
| Height of lift . . . . . (722 feet) | | 220 metres. |

The pressure valve in the rising column being about 7 metres above the shaft pump, the pump draws from a cistern supplied by the air-pump, which also does duty as a bottom suction lift. The water-level in this cistern is kept at a constant height of about 2 metres above the wind bore of the main pump, which is an important advantage as regards regularity of working. Riedler valves are used on the pump side, but the steam distribution is effected by a modified form of Corliss gear patented by Strnad of Berlin. In this system two ordinary Corliss valves are used in each cylinder, the whole of them being controlled by a single eccentric; but in the high-pressure cylinder provision is made for varying the steam admission by special cut-off valves placed within the main valves and working on the same centre from an independent eccentric, this arrangement being generally similar to that of the Meyer expansion slide, but arranged for a rocking instead of a straight line motion. Steam at 6½ atmospheres to 7 atmospheres effective pressure is supplied from boilers at the surface by wrought-iron pipes 87½ millimetres in diameter, terminating below in a large steam-drier which connects with the steam admission-valve by a passage of 130 millimetres in diameter.

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The steam pipe, which is protected by a covering of silk waste and an outer casing of sheet zinc, has a total surface, including that of the steam-drier, of about 76 square metres, and the amount of steam condensed averages about 1·5 kilogram per square metre per hour; the loss of pressure from the boiler to the engine is about 0·13 atmosphere. The engine was constructed by Messrs. Breitfield, Danek & Co., for a guaranteed maximum consumption of 9·4 kilograms feed-water per indicated HP. per hour—apart from the condensation in the steam-pipes. Several trials have been made, the results of which are contained in the following Table:—

| No. and Date of Trial. | II. 4 June, 1898. | III. 7 June, 1898. | IV. 25 November, 1898. | V. 17 November, 1898. | Totals and Means. |
|---|---|---|---|---|---|
| Duration in minutes . . | 165·00 | 180·00 | 180·00 | 233·00 | 758·00 |
| Revolutions per minute . | 49·20 | 48·52 | 50·94 | 51·60 | 50·20 |
| I.HP. . . . . | 95·49 | 94·17 | 100·01 | 100·31 | 98·04 |
| Total feed-water, kilograms . . . . . | 2,736·00 | 2,897·00 | 2,735·00 | 3,729·50 | 12,097·50 |
| Condensation in main, kilograms . . . . | 343·00 | 397·00 | 300·00 | 398·50 | 1,438·50 |
| Actual feed-water, kilograms . . . . . | 2,393·00 | 2,500·00 | 2,435·00 | 3,331·00 | 10,659·00 |
| Feed-water per I HP. hour, kilograms . . | 9·11 | 8·85 | 8·12 | 8·47 | 8·61 |
| Ditto per HP. efficient hour . . . . . | 11·58 | 11·26 | 10·45 | 10·90 | 11·02 |

The effective discharge of the pump is about 98 per cent. of the theoretical volume, and the effective 77 per cent. of the theoretical horse-power. The friction of the water in the rising main, which is 150 millimetres in diameter, when the engine is making 50 revolutions per minute, giving 1·48 metre per second, corresponds to a head of 10·5 metres, or about 4·8 per cent. of the actual lift.

H. B.

## *Direct Registration of the Discharge of Ventilating Fans.*

E. MURGUE.

(Comptes rendus mensuels de la Société de l'Industrie Minérale, May, 1899, p. 81.)

In the fiery mines of the Saint Etienne district the use of continuous self-registering indicators of the exhaust-air pressure, as well as of the speed of the fan, is now compulsory; a comparison of the two diagrams affording a means of controlling the state of the air-circulation in the mine. The indications afforded by this method are, however, only indirect so far as the main object to be determined, namely, the volume of air passing out of the mine, is concerned; for, supposing the return-airway to be suddenly

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blocked by a fall of ground, the fan-engine being under the control of a governor would continue to run nearly at its regular speed, and the water-gauge would not show any great variation from its average level, even although no air was passing through the workings at the time. In order to obtain a more direct method of measurement, the Author has designed a new instrument, giving a continuous diagram of the quantity of air passing, which has been successfully used for two years in the mines of the Montrambert Company under his management. This is essentially a water-gauge, with the top of each limb connected by an independent tube with the intake drift of the fan, one of these tubes A being straight, while the other B is converted into a Pitot tube by turning over a short length at the end into a horizontal limb facing the direction of the air-current. The pressure transmitted by A will therefore be less than that by B, as in the latter the loss of head due to the velocity of the current is reproduced as pressure by the impact of the entering air against the bend of the tube, and the difference of level in the measuring fluid (water or mercury) in the two limbs will directly indicate the function of the velocity $\frac{v2}{2g}$, and from it the volume of air passing may be determined, as the difference of level is a function simply proportional to the square of the discharges, or

$$h = \mathrm{K}\, v^2,$$

the coefficient K being compounded of all the constants influencing the result, such as section of airway, density of the air, etc., which are determined by a preliminary measurement in the usual way. The displacement expressed in column of water is, however, very small when the tubes are placed in the main airway, being only 1 millimetre to 1½ millimetre for a velocity of 4 metres to 5 metres per second, but by placing them in the eye of the fan intake, where the velocity of the air is from 10 metres to 12 metres, a difference of 6 millimetres to 8 millimetres is obtained, which is sufficient for the purpose of a self-registering instrument when properly amplified. The instrument is extremely simple, consisting of a rectangular zinc box, closed at the top, and divided into two unequal compartments by a diaphragm reaching nearly to the bottom, which is immersed in a cistern of water, the larger compartment being in communication at the top with the B, and the smaller one with the A tubes. As the pressure on the former is greater than that on the latter, the level of the water-level will be raised in the smaller compartment in proportion to the difference, and the movement is transmitted by a large cylindrical float through a vertical stem to a long lever parallel at one end to the outside of the cistern, and connected at the other with the pencil arm of a Richard registering apparatus, which draws a continuous diagram upon a band of paper travelling at the rate of 5 millimetres per hour. The paper is divided to show cubic inches

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per second through a range from 0 metre to 30 metres, the scale divisions being computed according to the law of the square. The paper is supplied in lengths suitable for a week's work, a fresh one being placed on the stem every Monday, the zero part of the instrument being adjusted at the same time. The instrument has proved to be extremely sensitive, perhaps rather too much so, with the inconvenience of sometimes giving confused diagrams. Attempts have been made to reduce the oscillation by interposing between the tubes and the pressure-gauge a closed vessel of 50 litres capacity, but without any very beneficial result. When the ventilator is stopped the pencil does not fall to zero, as the indicator is sufficiently delicate to show the amount of air-circulation due to natural ventilation.

H. B.

*Use of Dense Liquids in the Analysis of Coals.* MAURICE.

(Comptes Rendus de la Société de l'Industrie Minérale, June, 1899, p. 144.)

This is a long memoir on the application of salt solutions denser than water to the rapid determination of water and incombustible matters in small coal as a means of controlling the operation of coal-washing, and also by more refined manipulation of obtaining more exact results comparable with those of chemical analysis. As regards the former, two principal uses are indicated, the first being a method of determining hygroscopic water in coal slack; a weighed sample of the coal is added to twice its weight of a solution of calcium chloride of specific gravity 1·40 in a cylindrical test glass, and the contents are stirred rapidly together and filtered. The specific gravity of the filtrate is then determined by densimeter or by specific-gravity bottle. The density is diminished by rather more than 0·002 for every unit per cent. of water contained in the coal. Thus 1 per cent. reduces it to 1·39722, 10 per cent. to 1·87383, 20 per cent. to 1·35088, etc. The result obtained with the densimeter may be considered accurate to about 0·5 per cent., but with the specific-gravity bottle more exact determination may be made than can be obtained by the ordinary method of drying in a hot-air stove.

For the second use, namely, the determination of the proportion of shale in small coal, the Author uses a rectangular metal box, 80 millimetres square and 300 millimetres long, closed at one end and divided in the middle by a hinged flap, which, under ordinary conditions, is kept open by a spring, but can be closed by a chain from the outside. The method of using it is as follows: The tare of the empty box being known, the bottom compartment is filled with a solution of an appropriate density, *i.e.*, one in which coal will float and shale sink, the flap is closed, a weighed sample of about 1 lb. of the coal is placed in the upper compartment and

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the box is filled up with the solution. The flap is then dropped, the contents of the box are stirred together rapidly with a piece of wood, allowed to stand for a few seconds for the shale to settle, and the flap is shut. The coal separated will be entirely contained in the upper compartment and is collected upon a drainer with holes of 2 millimetres or 3 millimetres in diameter, while the shale in the lower division when the solution has been poured off is weighed in the box, and gives, after the deduction of the tare, a close approximation to the amount of incombustible matters present. The whole operation requires only about 5 minutes. For coals containing a large amount of dust and for more exact work special modifications of the method are made which are described in detail. These involve the successive use of solutions of different densities. The salts that it is possible to use without having recourse to unduly expensive chemical products are contained in the following list, giving the density of their solutions in water when saturated at a temperature of 15° to 20° C.

| | Specific Gravity. |
|---|---|
| Calcium chloride | 1·411 |
| Zinc sulphate | 1·445 |
| Potassium bromide | 1·500 |
| Cupric chloride | 1·528 |
| Sodium bromide | 1·565 |
| Ferric chloride | 1·632 |
| Calcium bromide | 1·652 |
| Barium bromide | 1·712 |
| Potassium iodide | 1·734 |
| Zinc chloride | 1·740 |
| Sodium iodide | 1·810 |
| Cadmium chloride | 1·890 |
| Magnesium iodide | 1·910 |
| Barium iodide | 1·953 |
| Calcium iodide | 2·006 |
| Zinc iodide | 2·185 |
| Zinc bromide | 2·391 |

H. B.

## *Ironworks of the "Deutscher Kaiser" Company at Bruckhausen on Rhine.*

(Stahl und Eisen, vol. xix., June, 1899, p. 566.)

These works, which are among the largest and most productive of the Rhenish Westphalian district, date from the year 1890, the proprietors, who were originally a coal mining company, holding about 23½ square miles of coal-fields, containing at moderate depths numerous seams yielding gas, furnace and coking coals in large quantity. There are five groups of pits, several of which were only put down with difficulty, owing to the thickness of the covering measures, Nos. II and III shafts having only reached the coal after 7 years' and 8 years' work respectively. The present out-

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put is about 3,300 tons daily, which will in time be increased to 6,000 tons. The first portion of the works constructed in 1890 was the Siemens Steel Works, containing seven basic lined furnaces, producing about 11,000 tons of mild steel monthly, and on the successful winning of the coking coals in No. III pit, blast furnaces and basic Bessemer converters were added in 1895. The completed plan includes six blast furnaces, three of which are blowing, a fourth is in course of construction, and the remaining two will be added when the collieries are fully developed. They are 82 feet high, 19 feet 8 inches bosh, and 12 feet 6 inches hearth diameter, with a water-cooled ring placed at the junction of the boshes, with the stack wall, the hearth and boshes being built with carbon bricks. Five Cowper stoves 23 feet in diameter and 98½ feet high and two compound twin blowing engines, with 6½ feet cylinders and 5 feet stroke, are provided for each furnace, whose daily make is from 250 tons to 300 tons of basic metal, which is carried in the liquid state to the mixer for use in the basic Bessemer converters. The coking plant includes 256 ovens, of which 188 are at work and 68 building; the total output when completed will be about 30,000 tons of coke monthly, with 1,200 tons of tar, 400 tons of sulphate of ammonia, 300 tons of benzole as by-products. Wire ropeways are used for carrying the washed coal from the colliery to the ovens, and the coke from the ovens to the blast furnaces. The ore, which is mostly imported, is brought by railway from the landing-place on the Rhine at Alsen to a store pile at the back of the furnaces. The Bessemer plant includes four 15-ton basic converters, with a present output of 20,000 tons of ingots per month, and a powerful cogging mill in direct connection with the rolling mills arranged for the conversion of ingots into rails, billets, or medium-sized joists at a single heat. The six rolling mills are contained in a building covering about 11 acres, and have a total capacity of 30,000 tons of finished iron and steel per month. The accessory machinery, such as cranes, rail-finishing machines, etc., are for the most part served by electric motors fed by current from a central station containing three 500-HP. generators supplied with steam from boilers fired with the blast furnace gas. The ground taken up for the works covers about 1,500 acres, a large part being appropriated for workmen's houses, of which 300, providing for 1,500 separate dwellings, have been erected.

H. B.

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## *Large Forging-Presses.*

(Stahl und Eisen, vol. xix., July 1899, p. 606.)

Messrs. Breuer, Schumacher & Co., of Kalk, have recently constructed two forging presses, giving a maximum pressure of 10,000 tons each. One of these is intended for the Dillingen Iron Works, Saarbrücken, and the other for the Obuchoff Steel Works in St. Petersburg. The power obtained by steam-engines acting directly upon the pressure-pump is directed over three rams, which can be used either together, singly or combined in pairs, so as to give full, two-thirds or one-third power as required, each ram having its own steam-pressure pump. The four steel columns carrying the press are about 12 metres long and 150 tons weight; the upper box, containing the three press cylinders, weighs 150 tons, the lower movable part, with the rams and pressing face, 400 tons, and the anvil plate about 100 tons. The nuts fixing the different parts upon the columns are 1,200 millimetres in diameter; there are sixteen in all, with a collective weight of about 50 tons. The Obuchoff press, which is illustrated by two plates, is intended to be used in combination with two smaller ones of 2,500 tons collectively for side forging.

H. B.

## *Reduction of Gold Ores Containing Bismuth in Brazil.*

F. COIGNET.

(Bulletin de la Société de l'Industrie Minérale, 1899, p. 102.)

At Passagem, in Brazil, auriferous quartz associated with magnetic and arsenical pyrites and bismuth sulphide is treated by a combined method of concentration, amalgamation and chlorine extraction. The ore, containing when hand-picked about 9½ dwt. of gold per ton, is stamped and washed over blanket strakes, and the deposit on the blankets by further washing gives about 0·4 per cent. of concentrates suitable for amalgamation, and 2·9 per cent. of pyritic material requiring calcination. The former product, in charges of about 1 ton with 5 per cent. of its weight of mercury mixed to a proper consistency with water, is treated in revolving barrels for 18 hours or 20 hours. The amalgam is collected by emptying the barrel into a divided vat containing in the centre compartment about 4 cwt. of mercury, to which is added the finely divided particles recovered by washing the residues in dolly tubs. By a first filtration through cotton cloth a nearly liquid amalgam is obtained, which, when squeezed dry through leather and retorted and melted with borax and nitre, gives bar gold of about 914 fine, the foreign matters being principally bismuth and silver. As the

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mercury from the first filtration retains some bismuth and gold which make it inactive for use in amalgamation, it is revived by partial distillation continued until the foreign metals are concentrated sufficiently to crystallise out as a complex amalgam when cooled. This amalgam in the residue when filtered and retorted apart gives an alloy of bismuth with about 25 per cent. of gold which is shipped to bismuth refiners in England. The yield by amalgamation is very imperfect, only about 52¾ per cent. of the gold being recovered, and of this 10 per cent. is obtained as coarse gold in the battery boxes; but the methods of battery and copper-plate amalgamation have been found to be inapplicable owing to the presence of arsenic and bismuth in the battery slimes. The second and larger portion of the concentrates containing pyritic minerals is calcined to remove sulphur and arsenic, and treated in charges of 2 tons with bleaching powder and sulphuric acid in rotating barrels for about 6 hours when the contents are discharged into vats and washed with water until no sensible reaction is afforded with ferrous sulphate solution. The gold-bearing solution is thus acidified with hydrochloric acid and passes through precipitating vats containing cuprous sulphide which separates a brown precipitate containing gold, sulphur and some unchanged copper sulphide. The precipitate is subjected to a complex refining operation, including three fusions with lead and a final cupellation. The gold resulting is from 900 to 920 fine. Notwithstanding its complication, the precipitation with copper sulphide is preferred to that with ferrous sulphate on account of its greater rapidity, only 12 hours being required instead of 48. The yield by chlorination is about 94 per cent., and the total of the combined operations, concentration, amalgamation and chlorination, about 66 per cent. of the assay value of the ore.

H. B.

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## *Testing-Tank for Ship-Models at the Washington Navy Yard.*

D. W. Taylor, Naval Constructor, U.S.N.

(Engineering News, New York, 6 July, 1899, p. 2.)

This tank has recently been built by the United States upon the lines of that of Mr. W. Froude, who was the first to demonstrate the practicability of deducing the resistance of a ship from its model. The tank cost about £20,000, and is about 470 feet long. The models used are 20 feet long, and are towed by a travelling bridge capable of speeds up to 20 knots. The motive power is electricity, the control being regulated to great accuracy. There are in all three brakes upon the traveller. The first is brought into action by merely cutting off current to the motors, which thereby become generators, and take power at the expense of the

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inertia of the moving structure. This, however, would fail if the electric fuses became overheated. The next is a friction brake consisting of two well-oiled strips of iron, which can be made by hydraulic pressure to nip a shoe projecting from the carriage. The low coefficient of friction enables the stoppage to occur without undue jerking. The third is in case of emergency. A hydraulic cylinder of 16 inches diameter is submerged in the water of the tank, its piston being attached through a connection of wire cables to a hook, which engages with the carriage on arrival at a certain position near the end of its run. The piston-rod is tapered, and as it moves outwards through the round hole in the cylinder cover, it meets with an increasing resistance. A bypass is also made round the piston to avoid putting the whole of the water in the cylinder into motion at once. Very delicate apparatus is fitted to the carriage for measuring the resistance of the model. The pull is taken by a helical spring, the forward end of which is moved in either direction along a screw by an electric motor. A projecting pencil records the position of the forward end of the spring, and so registers the resistance of the model. The after-end of the spring is attached to a cross-head sliding between two stops, and the towing line is fixed to this cross-head. An electrical connection is made so that, when the cross-head touches one or other of these stops, the motor rotates in one direction or the other, whereby the cross-head is kept floating between the stops, and a true record of the pull is obtained. The spring is frequently calibrated by dead weights to eliminate any error due to changes in temperature. The models are made of varnished wood, cut out of the solid by special machinery, which exactly reproduces the design.

A. P. H.

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## *Deep-Sea Sounding Apparatus.*

CHARLES BRIGHT, Assoc. M. Inst. C.E.

(Engineering, 7 April, 1899, p. 451.)

Cooper & Wigzell's apparatus has the advantage of simplicity as compared with other sounding devices. The indication of depth depends only on the hydrostatic head over the instrument, and is independent of the speed of the ship, and all other considerations. The instrument is fitted with two graduated scales, one up to 200 and the other up to 1,000 fathoms, the change from one to the other being effected by means of a thumb screw; a pointer shows the maximum depth reached during submersion. The indicating apparatus consists essentially of a cylinder and piston. The piston is ordinarily held at one end of the cylinder by a German-silver spring. On submersion the water-pressure forces the piston along



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the cylinder, and at the same time pushes a marker along the two scales, the reading being taken from the one in use at the time.

Thus any number of soundings can be obtained without expense, the only necessary preparation being the return of the marker to zero after each preparation. The instrument is placed in a protecting case, below which is the sinker, weighing about 28 lbs. The rest of the apparatus consists of the line and winch. The line is made of galvanised steel wires, braided with hemp steeped in solution, and especially devised to avoid kinking or tangling.

A. P. H.

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## *Researches on New Explosive and Detonating Materials.*

Ugo Alvisi.

(Annali della Società degli Ingegneri e degli Architetti Italiani, January-February, 1899, p. 53.)

The effect of an explosive is known to vary, not only with the nature of the materials of which it is constituted, but also with the detonator by which the explosion is determined. The Author has investigated the influence of various detonators on the new explosive materials, of which the base is ammonium perchlorate, recently discovered by him. He finds that to attain the maximum effect with these explosives it is necessary to mix ammonium perchlorate with the fulminate of mercury used as detonator. Certain kinds of dynamite or of explosive gelatine mixed with perchlorate and fired with ordinary detonators, which may contain from 80 per cent. to 90 per cent. of fulminate, with 10 per cent. or more of potassium chlorate or nitrate, etc., give effects frequently not greater than would be produced by the same explosive without perchlorate; but if perchlorate is mixed with the detonator the effect is greatly increased. Details are given of a series of trials at Cugny and at Rome, from which it would appear that the bursting force of the detonator may be more than doubled by this addition. The most powerful detonator, for the explosives in ordinary use, was found to be 17 per cent. of ammonium perchlorate and 83 per cent. of mercury fulminate. For special purposes other proportions are recommended. For explosives containing picric acid, or picrates, or tri-nitrocresol, etc., with perchlorate, the detonator should consist of mercury fulminate, with perchlorate and either picric acid or a picrate. Such explosives are specially adapted for use in torpedoes.

G. J. B.

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## *The Influence of a Magnetic Field upon a Ray of Light Traversing Certain Metallic Vapours.*

Prof. D. MACALUSO and Dr. O. M. CORBINO.

(Nuovo Cimento, vol. viii., 1898, p. 257.)

A flame, rich in the vapour of sodium or lithium, is placed between the poles of an electro-magnet, and traversed by a ray of plane-polarized sunlight. The absorption spectrum is observed by means of a Rowlands grating and a powerful eye-piece. When the current is turned on, a series of bands alternately bright and dark appear on each side of the absorption lines. A minute examination shows that in the region of these bands the primitive plane of polarization of the light is rotated through an angle which increases from zero up to 270° at the edge of the absorption line.

The breadth and distance of the bands from the axis of each line increases with the width of the line, but the number of the bands remains constant and the maximum rotation is unaltered at the edge of the line. It was found that close to the lines the light is circularly polarized. The Authors consider that the effect of the magnetic field is to produce a difference of velocity and of absorption in the two circular components into which the primitive rectilinear vibrations of the light are resolved.

G. J. B.

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## *On the Adhesion of Metallic Filings under the Action of a Current.* THOMAS TOMMASINA.

(Archives des Sciences Physiques et Naturelles, vol. vii., 1899, p. 57.)

A sphere of nickelled brass, 1 centimetre in diameter, is suspended by a fine metallic wire over the centre of a copper disk, 4 centimetres in diameter. The disk is supported by an elastic stem of copper, and the metallic filings having been placed upon it, the sphere is lowered until it just touches them, thus constituting a species of coherer. The apparatus is connected in the usual manner with a sensitive relay so arranged as to light up a small incandescent lamp whenever the current passes in the coherer. The Author finds that whenever this is the case, a slender thread of filings forms between the ball and the disk, and that by carefully lowering the disk this thread may be drawn out to a length of 2 centimetres without breaking. Various metals and alloys have the property to a different degree, the less oxidizable showing the phenomenon most easily. By a modification of the apparatus, briefly referred to in a note, the Author obtained filaments 105 millimetres in length with brass filings.

G. J. B.



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## *Models for the Illustration of Electro-Magnetic Phenomena.*

A. GARBASSO.

(Il Politecnico, January, 1899, p. 16.)

The Author advocates the use of models both for teaching purposes and, in certain cases, for the investigation of problems difficult to express in mathematical terms. He farther points out the analogy between a mechanical model and a mathematical expression when both are taken to represent the same physical phenomenon. In the apparatus employed by him electromotive force is represented by mechanical force, and quantity of electricity by angular displacement. Angular velocity corresponds to intensity of current, and moment of inertia and friction to self-induction and ohmic resistance respectively. Capacity is represented by a spring connecting certain of the moving parts, and there is an arrangement by which it can be varied during an experiment. Among the models is one for showing the law of divided circuits for instantaneous as well as for steady currents. Another apparatus illustrates the discharge of a condenser through two parallel circuits of different resistance.

The Paper is accompanied by photographs and drawings of the instruments, showing all the essential details.

G. J. B.

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## *Heat Produced by Parasitic Currents in Copper Conductors.*

GUIDO GRASSI.

(Il Politecnico, March, 1899, p. 164.)

The Author describes the experimental verification of his formula for calculating the energy absorbed by parasitic currents in copper conductors moving in a magnetic field. Representing by $w$ the number of watts per cubic centimetre of copper, by $n$ the frequency, and by B the maximum value of the induction, he gives the following formulas for the four cases considered:—

(1) Alternating field, conductor of rectangular cross-section with the side $\Delta$ normal to the direction of the field—

$$w = 9{\cdot}6 \times 10^{-11} \times n^2 B^2 \Delta^2.$$

(2) Alternating field, cross-section of conductor circular, of diameter $\Delta$—

$$w = 7{\cdot}2 \times 10^{-11} \times n^2 B^2 \Delta^2.$$

(3) Rotating field, cross-section of conductor rectangular with diagonal = D—

$$w = 10{\cdot}2 \times 10^{-11} \times n^2 B^2 D^2.$$

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(4) Rotating field, cross-section of conductor circular, of diameter $\Delta$—

$$w = 15{\cdot}4 \times 10^{-11} \times n^2 B^2 \Delta^2.$$

The numerical coefficients have been calculated by the Author on the hypothesis that the parasitic currents flow in circuits more or less elliptical instead of, as is generally assumed, in rectangular circuits. He maintains that the experimental results agree better with this formula than with those given by other writers. He measures the parasitic currents by determining their heating effect upon the conductor. For this purpose a bar of the metal of the required cross-section and about 5·5 centimetres long is enclosed in a glass vessel furnished with a capillary tube on the principle of Favre and Silbermann's calorimeter, water being used instead of mercury. The apparatus is calibrated by comparison with a standard thermometer, and its water-equivalent found. It is then placed in the field of a powerful electro-magnet and the heat generated by the parasitic currents determined by the expansion of the water in the capillary tube.

G. J. B.

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*The Transmission of Sound to a Distance.* A. SELLA.

(Nuovo Cimento, vol. viii., 1898, p. 261.)

A telephone is placed in the discharge circuit of a powerful influence machine without condensers, a short spark gap being used. On working the machine the rapid series of sparks produces a sound in the telephone. If now a beam of ultra-violet light is allowed to fall on the negative pole of the spark gap the sound is altered. By means of intermittent light a series of beats is produced which, if the periodicity is sufficiently rapid, coalesce into a sound the pitch of which corresponds to that of a string vibrating the same number of times per second.

As a source of ultra-violet rays the Author uses an arc lamp placed in the focus of a quartz lens, and at a considerable distance a second lens, also of quartz, concentrates the light upon the negative pole of the spark gap. The negative pole is a disk of platinized brass making an angle of 45° with the light, and the positive pole is a small ball of platinum, the arrangement being similar to the photo-electric receiver of Zickler.

The sounds may be rendered audible to a large audience by putting the secondary of a Ruhmkorff coil in series with the spark gap, and connecting the telephone with the primary, the coil acting as a step-down transformer. In the earlier experiments the flashes were produced by a disk with apertures, rotating in front of the light, but the Author has succeeded in obtaining the same result by reflection from a light mirror attached to the

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membrane of a phonautograph. When this is set in vibration by a sound, the displacement of the ray causes a sufficient variation in the intensity of the light falling upon the receiver to produce a corresponding note in the telephone.

G. J. B.

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### *Automatic Apparatus for the Continuous Distillation of Mercury.* A. G. Rossi.

(Nuovo Cimento, vol. viii., 1898, p. 296.)

This is a modification of the well-known apparatus for the distillation of mercury in vacuo, having for its object the removal from the distillation vessel of the gases occluded by the hot metal. Above the bulb in which the mercury is boiled there is a second bulb, connected with it by a narrow neck, and protected from the heat by a funnel-shaped screen. Condensation takes place in the upper bulb, but, owing partly to the narrowness of the neck and partly to the upward rush of vapour, the mercury collects there until a drop has formed, large enough to overcome the pressure and the surface tension. This drop is received by the funnel-shaped mouth of the vertical inner tube, which is thus made to serve as the fall-tube of a Sprengel pump, maintaining the vacuum and affording an exit for the products of distillation.

G. J. B.

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### *Commercial Manufacture of Liquid Air.*

(Engineering News, New York, 8 June, 1899.)

A plant will shortly be in operation in New York, capable of producing 1,500 gallons of liquid air per diem. In the ordinary process of cooling air, it is first compressed in a cylinder, then passed through tubes cooled by brine, and finally expanded to its original pressure, but at a much lower temperature. In the plant under consideration the process may be divided into two parts. The first is merely an extension of the ordinary compression and cooling system, the process being performed four times in succession. After the fourth repetition the air is at a pressure of 1,200 lbs. per square inch, and temperature of about 60° F., and the subsequent operation constitutes the special feature of the process. The air is passed into what is called the liquefier and after-cooler, consisting of two vessels, one above the other. In the top vessel are two sets of spiral tubes, one leading from the circumference to the centre, and the other from centre to the circumference. There is a connection between them through a throttle-valve. The air at 1,200 lbs. pressure enters the first spiral, and after

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flowing from the circumference to the centre, passes through the throttle-valve, its pressure being thereby reduced to 300 lbs. and greatly cooled. It now passes through the second spiral, which is in contact with the first, whereby the incoming air is cooled. This regenerative principle might be continued indefinitely, until the absolute zero of temperature were reached, but as soon as liquefaction occurs, the air is collected in the lower vessel. Any unliquefied air is again absorbed into the system. Difficulty is experienced in storing the liquefied air. One form of reservoir is surrounded by a jacket of volatilized liquid air. Liquid air may be used as a motive power, its volatilization producing great pressure without expenditure of fuel. Thus it may be employed for driving cooling-fans, the exhaust air from the motor being used as a cooling medium.

A. P. H.

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## *Limitations of the Present Solution of the Tidal Problem.*

J. F. HAYFORD.

(Science, vol. viii., 1898, pp. 810–814.)

The theory of the tides furnishes the periods, not the actual times of the occurrences of the tides, *i.e.*, the epochs of the components, not their range. The Author explains the nature of the problems by first assuming that the earth is a rigid nucleus, covered by a uniform depth of water, and that the moon always presents the same face to it. Coming nearer to the actual conditions, he finds that if the earth were covered with water up to the top of Mount Everest—that is, to a maximum depth of 10 miles—the mathematical solution, so far possible, would be almost intractable. The apparent rate of progress of the moon over the earth's surface is 17 miles per minute; the tidal wave would be able to follow the moon if the ocean had a depth of 13 miles. For depths varying between 10 and 5 miles, the rate of progress of the tidal wave would vary between 10 and 1 mile. The moon would tend to break down the old wave, and to build up a new one in advance of it. The actual conditions add to these difficulties a maximum sea depth of about 5 miles and reflections from exceedingly irregular shores. The real tidal wave moves northward in the Atlantic and part of the Pacific, and has an eastward tendency in at least two large areas, north of Europe and west of South America. In the Atlantic the semi-diurnal components are large as compared to the diurnal components; in parts of the Pacific they are small, so that the two tides of one day are of very different heights, and so that only one tide per day may result. At Batavia, *e.g.*, the component which has one high water per sidereal day is six times as large as the component having two high waters per lunar day. The conflicts

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with shores and bottom leave only the periods unaffected, the amplitudes are greatly changed. The effects of boundaries, bottom and sides, can best be studied in bays receiving tributaries of known depths, such as Chesapeake Bay, where complete data are obtained at Old Point Comfort, Baltimore, and Washington, and where observations are taken at forty-nine points on the bay, twenty-one along the Potomac, and sixty-one along other tributaries of the bay. The Author suggests a graphic, rather than an analytic, study of this comparatively unworked field of the problem as most promising for extending our knowledge of the tides. H. B.

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*Raymond-Barker's Insulation Test for Cable Joints.*

A. D. CONSTABLE.

(Electrical Review, vol. xliii., 1898, pp. 37–40.)

An illustrated description of a trough applicable to the test, and hints are given for intercepting possible leakage. An analysis is made of the electrical conditions, both of the simpler test and of the absolute *null* method, using Thomson-Varley slides. The insulation of the joint may not only be proved satisfactory or the reverse, but may be worked out in megohms. One of the condensers may be dispensed with. M. O'G.

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*Thermal Ammeter.* C. CAMICHEL.

(Séances Soc. Franç. Phys., vol. i., 1898, pp. 61–65.)

The thermal ammeter devised by the Author,[1] and recently improved, consists of a U-tube filled with mercury, and with one of its branches slightly drawn out in the middle. Into the narrow portion is introduced a mercury thermometer whose bulb is slightly less in diameter than the internal diameter of the tube. Two platinum electrodes plunge into the branches of the U-tube, and serve to convey the current to be measured. The heat developed is almost all concentrated round the thermometer, and the rise of the latter within a given time indicates the current strength. In the improved pattern, the U-tube is narrowed at its lowest portion, so as to produce a thin thread of mercury there. The thermometer bulb is made to enclose this thread, and thus measures the heating without loss by radiation. The heating is directly proportional to the square of the current. The apparatus as constructed measures currents from 1 to 0·05 ampere within 1 or 2 per cent. Its indications are extremely constant. E. E. F.

[1] Science Abstracts, 1899, No. 118.

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## *Magnets of Different Steels.* A. Abt.

(Weid. Annalen, vol. lxvi. part 1, 1898, pp. 116–120.)

This Paper contains a comparison of the magnetic moments of similar magnets made of different steels and magnetised in the same fields, the fields being increased step by step until all the magnets were saturated. The magnetic moment of the magnet of Wolfram steel is about twice that of any of the others. It loses its magnetism, however, faster than some of the others, losing 26·5 per cent. in 122 days.

J. B. H.

## *Meteorological and Magnetic Phenomena.*[1] V. Rijckevorsel.

(Philosophical Magazine, vol. xlvii., 1899, pp. 57–65.)

The Author has drawn curves showing the annual range of temperature, horizontal force, declination, vertical force, rainfall and barometric pressure for various stations in Europe. He finds a similarity between the curves for the various elements. Thus the maxima and minima are in general repeated in all the curves, though they sometimes occur earlier in some than in others.

From a consideration of the temperature curves for the various stations in Europe, particularly of the minimum in June and the maximum in July, the Author concludes that the June minimum is due to some disturbing cause travelling from the west coast of Scotland southwards, and the July maximum to a similar disturbing cause approaching Europe from the south.

The Author concludes that there is some common cause which rules all the meteorological and magnetic phenomena, and which influences them all in a similar way and almost simultaneously.

W. W.

## *Atomic Weights.* F. G. Wiechmann.

(Science, vol. ix., 1899, pp. 23–24.)

The Author gives the values which are recommended for adoption in analytical practice by a commission appointed by the German Chemical Society, consisting of H. Landolt, W. Ostwald, and K. Seubert. Some of these are given below. The last decimal

[1] Science Abstracts, 1898, No. 900.

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place may be regarded as accurate except in the cases of nickel, bismuth, and tin.

| Name. | Atomic Weight. | Name. | Atomic Weight. |
|---|---|---|---|
| Aluminium | 27·1 | Iron | 56·0 |
| Antimony | 120 | Lead | 206·9 |
| Arsenic | 75 | Magnesium | 24·36 |
| Barium | 137·4 | Manganese | 55 |
| Bismuth | 208·5 | Mercury | 200·3 |
| Boron | 11 | Nickel | 58·7 |
| Bromine | 79·96 | Nitrogen | 14·04 |
| Cadmium | 112 | Oxygen | 16·00 |
| Calcium | 40 | Phosphorus | 31·0 |
| Carbon | 12·00 | Platinum | 194 8 |
| Chlorine | 35·45 | Potassium | 39·15 |
| Chromium | 52·1 | Silicon | 28·4 |
| Cobalt | 59 | Silver | 107·93 |
| Copper | 63·6 | Sodium | 23·05 |
| Fluorine | 19 | Strontium | 87·6 |
| Gold | 197·2 | Sulphur | 32·06 |
| Hydrogen | 1·01 | Tin | 118·5 |
| Iodine | 126·85 | Zinc | 65·4 |

T. E.

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## *Carbon in Electrolytic Iron.* L. Houllevigue.

(Journal de Physique, vol. vii., 1898, pp. 708–709.)

Electrolytic iron is generally considered the purest that can be obtained; it is, however, far from being so. Besides the large quantities of hydrogen (100 to 150 times its volume) found in it, there are numerous other impurities. The Author considers the important one, carbon, and gives the result of experiments in which the soluble electrode consisted of a strip of steel with 0·4 per cent. of carbon, which was placed in a bath of chlorides of iron and ammonium. Heated to 900°, and tempered above 630°, this specimen of steel is composed of carbon dissolved in iron, but not combined; whilst the same steel, cooled slowly, is composed of pure iron and combined carbon. When the steel electrode was so treated as to be of the first class, electrolytic iron extremely poor in carbon was obtained (0·017 per cent. at the most). On the other hand, an anode of steel cooled slowly after being heated to 900° furnished an iron comparatively rich in carbon (from 0·033 to 0·035 per cent.).

Thus electrolysis appears to affect in a different way tempered steel and steel that is cooled slowly. Carbon dissolved in steel is not carried along with the current; it remains as a muddy deposit at the surface of the anode. Combined carbon, on the contrary, is carried along with the iron in the direction of the current. Combined carbon seems to constitute a complex iron, which is carried all-of-a-piece on to the kathode.

J. J. S.

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## *Electro-Metallurgical Industries of England.*

J. B. C. KERSHAW.

(Electricity, New York, vol. xiv., 1898, pp. 344–345.)

This article is a continuation of that previously noticed.[1] The works of the British Aluminium Company at Foyers, and of Messrs. Bolton and Sons, at Froghall and Widnes, are dealt with.

At Foyers, aluminium has been produced since June, 1896; 3,500 HP. is stated to be utilized between the two manufactures carried on there—aluminium and calcium carbide. The power is generated by five turbines, working under 350 feet head of water, each generating 750 HP. The armatures of the dynamos are keyed on to the same vertical shaft, and weigh 14 tons. Three more sets of generating machinery are to be installed. The total power available at Foyers will then be 6,000 HP. Details of the capital and profits of this Company are given.

At Froghall and Widnes, Messrs. Bolton and Sons carry on the electrolytic refining of copper. At Froghall, four Corliss valve triple expansion condensing engines are in use. These drive eight Elwell-Parker continuous-current dynamos, each 75 kw. Rope gearing is used. At Widnes two Galloway slow-speed engines drive by belts four dynamos similar in design and size to those at Froghall. The total production capacity of the two works is about 12,000 tons copper per annum.

Views showing the generating machinery at Foyers and at Widnes, and the copper-depositing vats at the latter place, are given.

AUTHOR.

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## *Synchronizer for Three-Phase Plant.*

(Electrical Review, vol. xliv., 1899, pp. 318, 319.)

The following ingenious arrangement, shown in the accompanying figure and due to Siemens and Halske, is used for synchronizing three-phase generators.

A and B are two switches, each provided with as many arms (3) as there are generators, and a corresponding number of contacts. Corresponding terminals of the generators and switch contacts are indicated by the same letters. By means of the switch B, the terminals of any incoming machine may be connected to the bus bars through the synchronizing lamps $L_1$ $L_2$ $L_3$. If the connections of the switch contacts were symmetrical, then the three lamps would at any instant be incandesced to the same extent. It will be noticed, however, that the connections are not symmetrical,

[1] Science Abstracts, 1898, No. 962.

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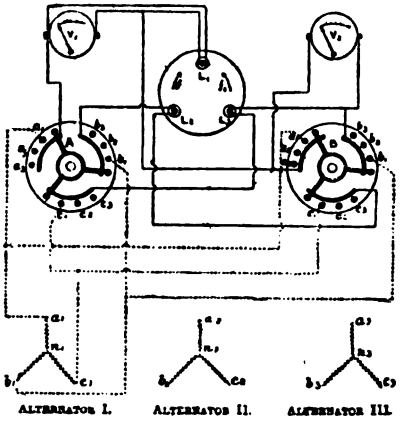
the long segment contact corresponding to $b_1$ $b_2$ $b_3$ in switch A being in connection with the segment corresponding to $c_1$ $c_2$ $c_3$ in switch B. The result is that when the *a* circuits of two machines happen to be in phase, so that—with the switches A and B in their proper positions—the lamp $L_1$ is extinguished, the *b* circuit of one machine is connected to *c* circuit of the other, and *vice versâ*, the lamps $L_2$ and $L_3$ being incandesced. If the machines are not running synchronously, the lamps will be extinguished consecutively, the extinction travelling round the triangle one way or




the other, according as the incoming machine is running below or above the speed of synchronism. The device therefore at once indicates whether it is necessary to increase or diminish the speed of the incoming machine. The main switch is closed at the instant when $L_1$ is dark, and when the rate at which the extinction travels round the triangle shows that the machines are running very nearly in synchronism. The voltmeters $V_1$ and $V_2$ are provided for greater sensitiveness.

A. H.

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## *Control of Distant Mechanism by Electricity.*

(Electrical Review, New York, vol. xxxiii., 1898, p. 298, pp. 305–308, p. 312.)

These articles give the full text of a recent patent in which Tesla sets forth his proposed method of steering and controlling ships by the use either of Hertz waves or of earth conduction. The coheror principle is the basis of most of the devices. Coherors, or their equivalents, govern the various relay-circuits which control the mechanism of the propelling and steering gear.

R. A.

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## *Electrical Survey in New York City.* A. A. KNUDSON.

(American Institution of Electrical Engineers, vol. xv., 1898, pp. 653–672.)

Details are given, with plans and tables, of an electrical survey made in New York City, U.S.A. It is shown that no appreciable leakage occurred from the open conduit tramway, in which an insulated return is used; but a steady potential difference of $\frac{1}{30}$ volt to $\frac{1}{10}$ volt between rails and earth was traced to the electric lighting systems and a variable potential difference to an overhead trolley line. The tram-rails were in general positive to water- and gas-pipes, the potential difference ranging from $\frac{1}{2}$ volt to 2 volts. At a terminus of the trolley line this potential difference increased to 10 volts, and here the rails were excessively corroded. The Brooklyn Suspension Bridge was generally 2 volts to 3 volts positive to earth; the probable effect of the resulting current upon the cables and anchor-plates is discussed, but not considered important. It is shown, however, that a very small potential difference may cause serious injury to pipes, &c., and that cast iron is by no means exempt.

A. H. A.

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## *Electric Vehicles and their Relation to Central Stations.* H. M. MAXIM.

(The Electrical World, vol. xxxiii., 1899, pp. 116–117.)

In this article the Author urges suppliers of current to give every facility for charging accumulators from their mains, as by so doing they will forward the more general adoption of motor vehicles, and cultivate what will eventually become an important addition to their customers. For the information of supply companies and accumulator manufacturers, it is stated that at present accumulators for vehicles should show a capacity of from 3·5 ampere hours to 4 ampere hours per pound of cell, complete with lugs, jar, etc., at a discharge rate of not less than 1·3 ampere per pound of complete cell. It must be possible to increase this rate to 4 amperes or 5 amperes per pound of cell for short periods without injury, and to effect complete charge in three hours or thereabouts. In France several firms are engaged in the business of letting out or caring for vehicles fitted with high-capacity batteries, for which there is a great demand. Motor cars should be of great use for such purposes as parcels' delivery, etc.

W. G. R.

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## *Electrically Operated Drawbridge.* W. KIDDE.

(Electricity, New York, vol. xv., 1898, p. 295.)

Since February, 1898, a 450-ton drawbridge over the Passaic River at Newark, N.Y., has been successfully operated electrically. The contractors were required to furnish power (from a 500-volt direct circuit) which would open or close the bridge in 30 seconds, this power not to be available until the wedges and locking device had been withdrawn; also the wedging and closing devices must be automatically cut off, so that they could not be used till the bridge is closed. These conditions have been successfully met, and the bridge operated by three unskilled men on their regular trips. Two cables are carried under the bed of the river up through the centre-pin of the bridge into a contact commutator under the roadway. The commutator has two parts, the lower consisting of a copper ring and central disk attached to, but insulated from, the stationary centre bridge pin. Over this is the heavy circular part which moves with the draw and carries on a diameter three insulated contact shoes, two of which are respectively held in contact with the ring and disk on the stationary part, and thus establish a lead and return to the motor-room above. The third shoe only touches the lower ring when the bridge is closed, and breaks contact by means of quick-acting springs directly the bridge begins to open; the circuit through this shoe and the centre disk drives the motor when operating the wedge shaft. The motor-room contains one motor with extended shaft to carry several clutches and gears. The first is the spur-wheel driving the line-shaft which operates the bridge, and is mounted on a friction clutch. Another clutch is attached by a sprocket-wheel and chain to the shaft for the locking devices and wedges. These two clutches are worked alternatively by a common lever, which also makes the requisite electrical connections. In mid-position neither clutch is in use.

The position of the wedges is indicated on a disk by a mechanism which also automatically interposes a latch bar in the arc of the clutch-lever, so that the bridge cannot be turned until the wedges have been withdrawn. An air-pump, connected to the motor-shaft by iron link belting, maintains 40 lb. pressure in a receiver for a signal whistle. The speed and direction of rotation of the motor are governed by a reversible controller, which regulates the speed with the different loads due to operating pump, wedges, and bridge. This controller and the clutch-lever are worked from a position overlooking the river. The drawbridge structure is 720 feet long, while the draw proper is 227 feet in length and 67 feet wide. The moving span weighs 450 tons. The Author suggests that the score of bridges close to one another over the Harlem River in New York city should be electrically operated from one central plant radiating power which would precede a ship in its passage through the successive draws. E. H. C.-H.

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## *San Gabriel Los Angeles Transmission Plant.* G. P. Low.

(Journal of Electricity, vol. vi., 1898, pp. 81–103.)

These works derive their power from the San Gabriel river in California. The intake is situated about 6 miles above the power-house; in summer the river appears to be nearly dry owing to the greater part of the water passing through the loose river-bed and flowing in it. To utilise this water an underground concrete dam has been constructed. This collects the underground water, which is passed into the conduit. The conduit consists principally of concrete-lined tunnel and wood pipe, the latter being 48 inches internal diameter built up of longitudinal wooden staves bound together with iron hoops; the pipes are laid 10 feet below the hydraulic gradient of the conduit, and are therefore always charged with water.

Four sets of turbines and generators are installed, each set yielding 550 HP. The turbines are of the Tutthill impulse type, with two bucket-wheels on a horizontal shaft; they run at 430 revolutions per minute under a head of 400 feet. The alternators are coupled direct to the turbines, and give two-phase currents at 500 volts.

The current is transformed up to 17,000 volts, and transmitted 23 miles along two three-wire circuits carried by poles; the wires are arranged in two equilateral triangles with 30-inch sides. The distribution is very complicated, the station working in parallel with three other sources of supply by means of transformers, motor generators, etc. Current is supplied in Los Angeles by the following systems:—(1) Single-phase 2,400-volt service for outlying districts; (2) two-phase 2,400-volt power service; (3) 500-volt direct current power service; (4) 220-volt direct current three-wire service. These different services, combined with the fact that currents reach the sub-station from four different sources at varying voltages, etc., make the switchboard arrangements exceedingly interesting.

The article contains a very detailed description of the work, and is fully illustrated.

M. G. W.

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## *Mixed System at Hanover.*

(Street Railway Review, vol. viii., 1898, pp. 801–802.)

This article is an abstract from a Paper read by T. Krüger at the Geneva meeting of the Permanent International Tramway Union. Information is first given as to the treatment of the cells. The batteries weigh from 4,400 lbs. to 5,500 lbs., and comprise two hundred and two cells with a capacity of 25 ampere hours at

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a discharge rate of 25 amperes. After running 5,000 miles to 7,500 miles the batteries are cleaned; when this is again necessary, new plates are fitted. Negative plates are re-pasted, the grid lasting through six "re-pastings," or 150,000 miles. The cost of re-pasting is 76 marks (£3 16*s.*) per car. New positives cost 707 marks (£35 7*s.*) per car. The cost of maintenance and renewals from 1st August, 1896, to 1st August, 1898, amounted to 0·405*d.* per car-mile. In order to obtain a long life of battery, it should be chosen so that not more than one-half the capacity will be required. The average life of batteries in thirty-seven cars was 23,417 miles; that of the positives in seven cars was 24,528 miles; and that of the negatives in two cars was 23,321 miles. Inspection and cleaning are essential. The power apparently costs ¼*d.* per car-mile when the batteries are in use, and ⅛*d.* per car-mile when not in use, in excess of that which would be required with a simple trolley. W. R. C.

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## *Nernst Electric Lamp.* J. SWINBURNE.

(Society of Arts Journal, vol xlvii., 1899, pp. 253–260.)

The light is obtained by rendering incandescent by means of an electric current highly refractory oxides worked up into little white rods. Each rod is mounted on two platinum wires by means of a paste made of refractory oxides. Such rods are, when cold, good insulators, but become conductors when heated. Since the rods fall in resistance as the temperature increases, an increase of current produces a decrease of resistance. This tends to give instability in running in parallel on supply circuits. This instability is corrected by a series resistance made up of fine wire, and amounting to 10 per cent. or 12 per cent. of the whole resistance of the lamp. The consumption, including resistance, is 1·5 watt per candle for large lamps, and 1·6 for small lights. The lamp will not light up of itself, since the rod is an insulator when cold, but may be started by warming with a match or spirit lamp. The small lamps and the lamps of medium size are in practice started by a heating resistance. This is arranged close to the rod and in shunt to it. As soon as the rod is hot enough to conduct, its current works a tiny cut-out in the resistance circuit. In large lamps the heating system is a little more elaborate, as the resistance arrangement is arranged as a sort of hood which covers the rod. As soon as the rod conducts, not only is the resistance circuit broken, but the electromagnet lifts the little hood clear off the rod. In all these forms the rod and its mounting are replaceable without interfering with the rest of the lamp. The Nernst lamp is cheaper as to maintenance than either glow-lamps or arc-lamps, and cheaper than the latter in first cost. W. G. R.

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## *Space Telegraphy (Inductive).* S. EVERSHED.

(Journal of the Institution of Electrical Engineers, vol. xxvii., 1898, pp. 852–869.)

The Author gives fundamental formulas for the induction in secondary coil when telegraphing by horizontal rectangular coils. To get the greatest mechanical energy in the secondary, the impressed electromotive force must be in step with the current, and the condition for maximum activity of a motor must be fulfilled, viz., the back electromotive force must equal half the impressed electromotive force. The readable current in a Gower-Bell receiver was found by measurement to have a maximum (crest of wave) value of $2{\cdot}9 \times 10^{-6}$ amperes. The most audible frequency is 400, but the Author anticipates that at this speed absorption by the earth will rapidly damp out the waves.

An ingenious relay receiver is described. It consists of a rectangle of wire having one end free to vibrate in a permanent magnet field. A current of the proper frequency will swing the rectangle into contact either with a stop or another similar rectangle vibrating. The amplitude is proportional to the impressed electromotive force. When electromotive force and current are in the same phase, the power available in the secondary working a telephone at $400\sim$ is 600 times greater than that available in the rectangular relay at $16\sim$.

M. O'G.

## *Wireless Telegraphy.* A. TURPAIN.

(Comptes Rendus, vol. cxxvii., 1898, pp. 1,208–1,210.)

This Paper considers the simultaneous transmission of signals along one wire to different stations by using Herzian waves of different wave-lengths and having resonators at the different stations, each one tuned to receive only the waves of one wave-length.

The principal of interference is used to stop or start the transmission of waves of any particular wave-length along the wire from the particular resonator at the transmitting station. The two wires from the terminals of the resonator are joined together and then to the line wire; but between the resonator and the line wire a side branch, equal in length to one-half the wave-length, is inserted in one of the terminal wires. According as this branch is short-circuited or not, the resonator at the far station receives the signals or is silent. (This may be *vice versâ*, depending on the system of resonators.)

An experimental installation with a line 170 metres long, having three stations on it, was erected, and by the aid of five resonators simultaneous and independent communication was obtained between every two stations.

J. B. H.



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## *London-Birmingham 76/0·096 Telephone Cables.*

(Electrical Review, vol. xliv., 1899, pp. 128–131.)

The conductors weigh 160 lbs. per mile, and measure 96 millimetres diameter; the resistance per mile at 60° F. is 5·852 standard ohms. The pairs are made up with a lay of 12 inches. The arrangement is:—Centre, one pair; first layer, six pairs; second layer, twelve pairs; third layer, nineteen pairs. The lead tube is 160 millimetres thick and 2·625 millimetres diameter. The capacity per mile of each wire with all others to earth is 0·1 microfarad at 50° F. The wire-to-wire of a pair capacity is 0·065 microfarads per mile. The cable is drawn into 3-inch pipes in 150-yard lengths. Illustrations are given of jointing and of the test pillars where dry air may be pumped in.

M. O'G.

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## *Fluid Motion.* H. S. Hele-Shaw.

(Engineering, vol. lxvii., 1899, pp. 28–30.)

The motion studied takes place between two parallel sheets close together. Stokes has proved mathematically the very remarkable fact that, under these conditions, the lines of flow are the same as would be given by a perfectly frictionless or viscid liquid. The Author shows the stream lines experimentally, under various interesting conditions, by introducing coloured liquid at suitable points. The Paper contains some fascinating reproductions of photographs.

A. Gs.

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## *Speed Indicator.* W. H. Browne, Jr.

(Electricity, New York, vol. xv., 1898, p. 35.)

This instrument, made by the Weston Electrical Instrument Company, comprises a small permanent magnet dynamo with a carefully laminated drum-wound armature, which works with flat side-bearing copper brushes so as to permit rotation in either direction, longitudinal motion of the armature being prevented by set collars. The armature spindle is connected to the machine, a dynamo for example, whose speed it is desired to measure, by means of a flexible "dentist's" shaft of sufficient length to remove the indicator from the magnetic field of the dynamo, the other end of the flexible shaft having a split externally roughened pin which can be pushed into a hole in the end of the dynamo shaft. The instrument is connected to a high resistance voltmeter, and,

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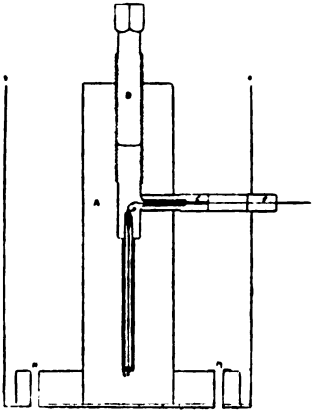
by properly setting the brushes, a straight-line characteristic can be obtained for either right- or left-handed rotation. An accuracy of one revolution in 1,500 can be obtained. It has worked satisfactorily for nine months at the University of Nebraska.

C. K. F.

*High-Pressure Piezometer.* A. de F. PALMER.

(American Journal of Science, vol. vi., 1898, pp. 451–454.)

An apparatus for measuring very high pressures may be based upon the known relations between the electrical resistance of mercury and the pressure upon it. The apparatus is shown in the diagram, where A is a Bessemer steel cylinder firmly keyed to a cast-iron collar having holes, H H, for anchor bolts. D is a capillary glass tube, 0·1 millimetre in internal diameter and



8 centimetres long, filled with pure mercury electrically connected with A by a globule of mercury E. A platinum electrode, sealed into the top of D, is soldered to a silk-covered copper wire that passes out of A through a marine glue plug in the tinned steel screw, C, and forms the upper connection with a Wheatstone's bridge. Pressure may be obtained and measured up to 3,500 atmospheres.

E. E. F.



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## *Metallic Reflection.* E. HAGEN and H. RUBENS.

(Berlin Phys. Gesell. Verh., vol. xvii, 1898, pp. 143–147.)

The method employed facilitates the measurement of reflective power when the incidence is very nearly vertical, thus eliminating the errors due to polarization. The reflection is not measured in its total extent, but for the separate colours by means of a spectro-photometer and Maxwell's eye-piece slit. The metals are examined in the shape of concave mirrors, near the centre of curvature of which a glowing platinum wire is mounted. An image of both the wire and its real image is projected upon the double slit of the spectro-photometer, so that the two can be directly compared.

The results are given in the following Table, where the figures denote the percentage of light of various wave-lengths reflected by the metals in question:—

| For $\lambda$ = | 450 | 500 | 550 | 600 | 650 | 700 $\mu\mu$ |
|---|---|---|---|---|---|---|
| **A.—Pure metals.** | | | | | | |
| Silver | 90·6 | 91·8 | 92·5 | 93·0 | 93·6 | 94·6 |
| Platinum | 55·8 | 58·4 | 61·1 | 64·2 | 66·3 | 70·1 |
| Nickel | 58·5 | 60·8 | 62·6 | 64·9 | 65·9 | 69·8 |
| Steel, hardened | 58·6 | 59·6 | 59·4 | 60·0 | 60·1 | 60·7 |
| Steel, unhardened | 56·3 | 55·2 | 55·1 | 56·0 | 56·9 | 59·3 |
| Gold | 36·8 | 47·3 | 74·7 | 85·7 | 88·2 | 92·2 |
| Copper | 48·8 | 53·3 | 59·5 | 83·5 | 89·0 | 90·7 |
| **B.—Speculum metals.** | | | | | | |
| Alloy of Ross (68·2 per cent. Cu + 31·8 Sn) | 62·0 | 62·9 | 64·0 | 64·4 | 65·6 | 68·1 |
| Alloy of Brashear (ditto.) | ,, | ,, | ,, | ,, | ,, | ,, |
| Alloy No. 1 of Schröder (66 per cent. Cu + 22 Sn + 12 Zn) | 62·4 | 62·5 | 63·4 | 64·2 | 65·1 | 68·0 |
| Alloy No. 6 of Schröder (60 per cent. Cu + 30 Sn + 10 Ag) | 61·5 | 62·5 | 63·6 | 65·2 | 66·6 | 68·6 |
| **C.—Glass mirrors.** | | | | | | |
| Backed with silver . from | 79·3 | 81·5 | 82·5 | 82·5 | 83·5 | 84·5 |
| ,, ,, . to | 85·7 | 86·6 | 88·2 | 88·1 | 89·1 | 89·6 |
| Backed with amalgam | 72·8 | 70·9 | 71·2 | 69·9 | 71·5 | 72·8 |

The reflective power increases in general with the wave-length, especially in the case of gold and copper. Iron shows a minimum at 550 $\mu\mu$.

E. E. F.

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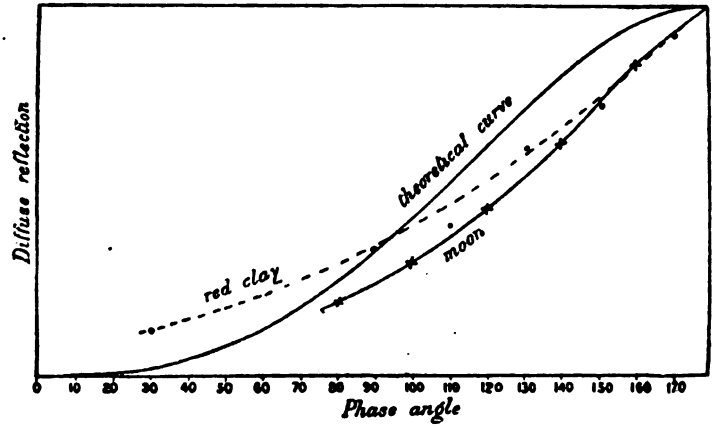
## *Irregular Reflection.* C. C. Hutchins.

(American Journal of Science, vol. vi., 1898, pp. 373–380.)

The reflecting powers of various dull surfaces were studied by means of the thermograph, so as to obtain the total energy reflected. The source of light was the sun. The diagram shows the reflection from a sphere of red clay and from the moon at




various phase angles, as compared with the reflection postulated by Lambert's law. The following Table shows the albedo of various bodies investigated:—

| | Albedo. |
|---|---|
| Plaster | 32·7 |
| Magnesia | 47·6 |
| Paper | 82·5 |
| Green leaf, upper side | 30·2 |
| Green leaf, under side | 38·0 |
| Volcanic rock | 27·4 |
| Brown soil | 31·7 |

E. E. F.

## *Dilatation of Perfect Gases.* D. Berthelot.

(Comptes Rendus, vol. cxxviii., 1899, pp. 498–500.)

The Author discusses the coefficient of dilatation at constant pressure, denoted by $\gamma$, common to gases. The generally accepted value has been $\gamma = \frac{1}{273 \cdot 14}$. Some of the German physicists have recently, says the Author, proposed to raise this figure to 274, or even 274·5. He refers to recent researches of Chappuis, Amagat,

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Leduc, and Sacerdote, made with regard to hydrogen under pressures from 1 millimetre of mercury to 100 atmospheres. These, he says, restore the classical number 273·14, or 273. Some interesting relations are mentioned arising from the fact that for hydrogen $\gamma$ in the perfect gas is greater, for other gases less, than $\alpha$, the corresponding coefficient under atmospheric pressure.

S. H. B.

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## *Regnault's Calorie and the Specific Volumes of Steam.*

G. P. Starkweather.

(American Journal of Science, vol. vii., 1899, pp. 13–33.)

Regnault's determination of the specific heat of water and the total heat of steam, together with the results of ten other experimenters, are first discussed at length. It is found that Regnault's thermometric scale was that of the air-thermometer; that his calorie represents the specific heat at 15° on this scale; that with this unit his experiments give 1·00358 for the mean specific heat between 0° and 100°, and for the "heat of water,"

$$h = t + 0{\cdot}00000929\,t^2 + 0{\cdot}000000265\,t^3 \quad \text{above } 100°$$
$$= 1{\cdot}00449\,t - 0{\cdot}0001904\,t^2 + 0{\cdot}000001813\,t^3 \quad \text{below } 100°;$$

that the "total heat of steam" is best represented by

$$H = 603{\cdot}2 + 0{\cdot}356\,t - 0{\cdot}00021\,t^2 \quad \text{above } 100°$$
$$= 598{\cdot}9 + 0{\cdot}442\,t - 0{\cdot}00064\,t^2 \quad \text{below } 100°.$$

The difference between these quantities gives the latent heat, from which, with Rowland's value of J, viz., 427·03 kilograms at Paris at 15°, the following values of the specific volumes of dry saturated steam have been calculated :—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0° | 208·94 | .. | .. | .. | .. | .. | .. |
| 10 | 107·88 | 60 | 7·6703 | 110 | 1·1973 | 160 | 0·30278 |
| 20 | 58·505 | 70 | 5·0320 | 120 | 0·88099 | 170 | 0·23982 |
| 30 | 33·098 | 80 | 3·3942 | 130 | 0·65948 | 180 | 0·19216 |
| 40 | 19·637 | 90 | 2·3464 | 140 | 0·50152 | 190 | 0·15566 |
| 50 | 12·063 | 100 | 1·6587 | 150 | 0·38707 | 200 | 0·12739 |

The error of these numbers cannot be more than 0·5 per cent. on the score of the value of J, nor more than 0·6 per cent. at 200°, 0 per cent. at 100°, 0·5 per cent. at 0° from uncertainty as to the latent heats; below 40° the numbers are entirely uncertain, owing to errors in Regnault's values of $p$ and $\frac{dp}{dt}$.

The volumetric experiments on superheated steam made by

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ten observers, in which an unusual amount of difficulty occurs by reason of condensation on the walls of the containing vessel, are then minutely discussed with the conclusion "that all our knowledge concerning the density of steam is limited to the saturation line, the experiments on superheated steam presenting discrepancies which cannot be reconciled."

R. E. B.

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## *Carbon Coherer.* T. Tommasina.

(Comptes Rendus, vol. cxxviii., 1899, pp. 666, 667.)

When brass filings are suspended in water and a feeble current is sent through, the filings form chains, which break up subsequently, not into individual particles, but into short rods. The Author attempted to find a substance which would under similar circumstances break up into particles. He succeeded in forming carbon chains 12 to 15 millimetres long, and produced a carbon coherer which had a sensitiveness as great as that of the best metallic coherers. They have the advantage of losing their conductivity with the least shock, and, under favourable conditions, the interruption of the current through the coherer suffices to restore the original resistance. Another efficient type of carbon coherer may be made by introducing two cylindrical arc carbons into a glass tube, in which they are held by rubber stoppers in such a position that their ends are lightly in contact. Such a coherer is extremely sensitive, and does not easily get out of order. The Author employed this coherer to test whether any extra currents were induced in the human body by electric oscillations. On holding the terminals between his thumbs and forefingers, he found that the coherer acquired a high conductivity by the impact of electric waves.

E. E. F.

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## *Chemical Properties of Aluminium.* A. Ditte.

(Comptes Rendus, vol. cxxviii., 1899, 195–201.)

In a former Paper[1] the Author showed that aluminium is dissolved by a solution of common salt, provided some weak acid is present. In this Paper the oxygen abstracted by the solution from the air is shown to materially hasten the action, especially near the surface of the liquid. When no acid is introduced into

[1] Science Abstracts, 1899, No. 847.

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the solution, the carbonic acid which the liquid abstracts from the air can fulfil its purpose, and hence it is that aluminium is slowly dissolved in salt water exposed to the air. The action in the case of sea water containing, besides common salt, other chlorides and also bromides is considered.

J. B. H.

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## *Progress of Aluminium.*

(The Engineer, vol. lxxxvii., 1899, pp. 155, 156.)

This article describes the advance made in the extraction and treatment of aluminium during the last 2 years, and *inter alia* refers at length to Wallace's Paper before the Soc. Chem. Ind.[1] The yield of aluminium by the Héroult process is now 1 lb. per 12 E.HP. hours, with a pressure of 3 volts to 5 volts and a bath-temperature of 750°–850° C. Accepting Thomson's figure for the atomic weight of Al (26·77 when H = 1) and the theoretical voltage of the Héroult cell as 2·4 (obtained by deducting 0·65 volt, the electrical equivalent of the heat of formation of carbon monoxide, from 3·05 volts, the theoretical electromotive force of liquid alumina), the theoretical output of Al per E.HP. day of 24 hours is 5·487 lbs. Taking the mean (4) of Wallace's voltages, the 'energy efficiency of the process is 36·45 per cent. and the current efficiency is 60·07 per cent. Two or three years ago these members were 22·7 and 40·6 per cent. respectively.

The proposal made in 1892 by Chatterton for the application of power obtainable from the Periyar Irrigation Works (in India) to the production of aluminium has not yet been taken up. But, meanwhile, Chatterton, by teaching the methods of working the metal in the Madras College of Engineering, is accustoming the natives of Southern India to the use of aluminium, and so preparing a demand which in time may lead to the establishment locally of a new electric smelting industry. Hunt has claimed[2] that with aluminium at 29 cents per lb. it can compete with copper for conductivity purposes, and with wire for a given current would show for the same cost a gain of 52 per cent. in weight and of 60 per cent. in strength, with an increase of 26 per cent. in diameter. He reckoned the conductivity at 63 (Cu = 100). Kershaw, taking the conductivity at 59, and with certain other data, finds[3] the Al to be $1\frac{1}{3}$ times as costly as Cu. Accepting Lord Kelvin's latest determination of conductivity (60·5 per cent. for 99·7 per cent. Al), the true electrical capability of the metal would lie between Hunt's and Kershaw's figures. Russell estimates an increase of 10 per cent. to 15 per cent. in cost against aluminium. But the

[1] Science Abstracts, 1898, No. 961.
[2] *Ibid*, 1898, No. 437.
[3] *Ibid*, 1899, No. 169.

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two metals can only come into competition for bare wires, as the comparatively great diameter of Al conductors necessary for a given current capacity militates against the economical use of this metal for insulated wires. Nevertheless aluminium has been used for telephone work, and at Foyers and Pittsburgh and in Germany it has been employed for heavy currents apparently with success. It is also to be used to conduct a 30,000 volt current from the generating station of the Snoqualmie Falls Power Company to Seattle and Tacoma, 20 miles distant. The principal use for aluminium is in the iron and steel foundry, where it is very commonly added in small quantities to the metal immediately before casting. The next largest field is in the manufacture of cooking utensils. Opinions differ as to the utility of aluminium for shipbuilding. As Ristori has shown, a part of the prejudice against it is traceable to the early use of an alloy of Al with 6 per cent. Cu, which, naturally, was rapidly corroded in salt water. Nevertheless the metal has been unduly corroded, even where not in contact with more electro-negative metals, on the sheathing of the yacht "Defender"; and the cause of this has not yet been explained. The Spanish-American war has demonstrated the value of the metal as a substitute for inflammable wood in warships. The soldering of aluminium is inevitably a trouble, as all the solders of sufficiently low fusing-point are electro-negative to the metal. Autogenous soldering, however, does not suffer from this defect. The metal is now being extensively used in place of lithographic stones.

W. G. M.

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*Accumulator Tests.* P. SCHOOP and H. BENNDORF.

(Elektrochem. Ztschr., vol. v., 1898, pp. 133–149 and pp. 157–166.)

The Paper contains a detailed account of tests carried out on three different types of secondary cells. It is pointed out that the relative merits of various types of cells cannot be arrived at from an investigation of their behaviour during a test, unless the particular purpose for which the accumulator is required is known. In the tests described an auxiliary electrode of cadmium was used, and the following quantities were observed, in the order given:—(1) Potential difference between cadmium and spongy-lead electrodes with current passing through cell; (2) also on open circuit; (3) potential difference between peroxide and cadmium electrodes when current was flowing through cell; (4) also on open circuit; (5) potential difference between terminals of cell; (6) electromotive force of cell. All these results are tabulated, and plotted in the form of curves. A comparison of the cells as regards capacity, etc., is obtained by determining the capacity per kilogram-weight of cell in each case. The Authors

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particularly insist on the advantage of using an auxiliary cadmium electrode, as by means of it it is possible to determine which of the two plates gets exhausted sooner; such information may lead the manufacturers to considerable improvements in the construction of the cell.

A. H.

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*Prevention of Collisions at Sea.* G. Dary.

(Électricien, vol. xvii., 1899, pp. 17–19.)

An invention by H. Herbert is described, in which two or more thermopiles are mounted on a vertical shaft capable of rotation; they are shielded so as to exclude all air-currents, and all radiations, from the ship and from solar rays, whether direct or reflected from the surface of the water. The thermopiles are supposed to receive radiation from any approaching ship, and actuate relays of the D'Arsonval galvanometer type, ringing a bell when pointing in the direction of the approaching object.

E. C. R.

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*Electrical Apparatus on U.S. Battleships.* F. W. Roller.

(Electrical Review, New York, vol. xxxiv., 1899, p. 13.)

In this Paper the performance of the various types of electrical apparatus used on shipboard in the recent war is discussed. It was found that indicating apparatus of the galvanometer type was not satisfactory. The electric firing device for rapid-fire guns worked very well on the "Nashville." Signalling was carried on by means of the "Ardois" apparatus, which consists of a string of four lanterns, each half clear glass and half red; inside each were two lamps, either of which could be illuminated independently, the different signal-combinations being obtained by means of a keyboard. The search-lights, motors for ammunition hoists, turret-training, ventilating, fan-driving, and steering gear worked well.

C. K. F.

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*Economic Test of a Boiler Feed-Pump.* F. M. Wheeler.

(Mechanical Engineer, vol. ii., 1898, pp. 873–874.)

It has been shown that the steam consumption of a duplex feed-pump will average about 120 lbs. per I.HP. hour, while in the U.S.A. battleship "Minneapolis" some pumps consumed over 200 lbs. of steam per I.HP. per hour. The pump referred to in

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the Paper consumed 52 lbs. of steam per I.HP. per hour; the test was conducted by Messrs. Willans and Robinson, Rugby, and was for the benefit of the British Admiralty. The pump is a cross compound one; the valve gear is such that the low-pressure cylinder may be shut off, and the high-pressure side may act as a simple pump. The valve gear is fully described in the Paper. As regards economy, this particular pair of pumps with attachments weigh about ½ ton, and handle about 17,570 lbs. of feed-water per hour. The power of the pump, working compound, was 5·6 I.HP. On the basis of a saving of 70 lbs. weight of steam per I.HP. per hour over and above what would be used in a duplex pump, a total saving of steam of about 393 lbs. per hour, or about 50 lbs. of coal per hour, is effected. This gives a total saving of 1,200 lbs. of coal per 24 hours.

A. S.

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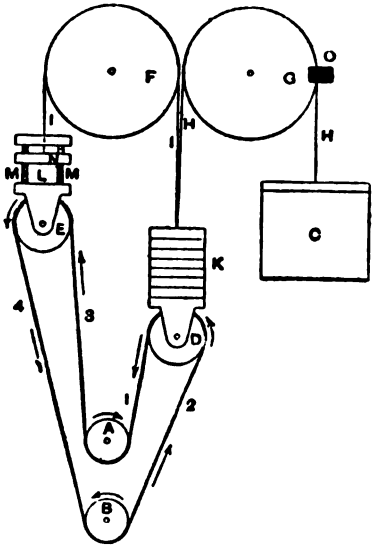
*Electric Elevators.* A. E. B. RIDLEY.

(Mech. Eng., vol. iii., 1899, pp. 58–60.)

In this article, the Sprague-Pratt and Ward-Leonard elevators are briefly described, together with one designed by E. M. Fraser,




wherein all gearing has been eliminated and the motors are never reversed, the brake being used only for braking the car. In this elevator, of which a diagram is given, pulleys on the shafts of

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two motors, A B, act on loops on an endless rope, 1, 2, 3, 4, whilst in other loops are idler pulleys, E D, attached to an adjustable frame L, and a counterweight K respectively, and both movable vertically in guides. C is the car, and O a brake clutch. If A rotates faster than B, D moves down and the car C up; whilst if B rotates faster than A, D moves up and the car C down. By varying the speeds of A and B, the car can be made to move up or down or to stop as desired.

C. K. F.

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## *Electrical Equipment of Refrigerating Plant.*

(American Electrician, vol. xi., 1899, pp. 1–5.)

The lighting, ventilating, elevating power and partial pumping service for the Manhattan Refrigerating Co.'s New York storage and distributing plant is entirely electrical. Within the building, the refrigerating medium is brine circulated by steam-pumps, but for the central station service to the adjacent market stalls liquid ammonia is used. The ammonia pumps are steam-driven, but the brine- and water-pumps are worked in pairs by 20 HP. belted motors at 250 volts, which have to operate in the wet. Switches and contacts are silver-plated to prevent chemical action with the ammonia or salt-laden atmosphere. Walls and ceilings being frequently snow-covered, special precautions had to be taken with conductors, which are twin-rubber and lead-covered, laid in steel pipe with outlet boxes filled solid with paraffin. Lampholders are of the porcelain waterproof type, hung by twisted cable from the outlet boxes. To get over difficulty with shocks from damp switches, a novel form of enclosed switch is used, consisting simply of a glass tube stoppered at both ends and containing a globule of mercury. When tilted in one direction the mercury joins the iron terminals, which pass through one of the stoppers. Forty 12-inch motor-fans are used for maintaining an even temperature throughout the storage rooms. A specially designed hanging waterproof bell has to be used with the telephones on account of the prevalent moisture.

E. H. C.-H.

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## *Power Station at Pittsburg.* G. F. Greenwood.

(Electrical World, vol. xxxiii., 1899, pp. 203–205.)

The consolidated lines were found to require a station capacity of 6,000 kilowatts, which was divided among six machines. Slow-speed horizontal engines were chosen as occupying less floor space than vertical engines. Their 20-foot fly-wheels weigh 100,000 lbs.

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Coal is handled by conveyors which can deal with 40 tons per hour, and take 15 HP. to operate. Each battery of water-tube boilers has a separate iron stack, 147 feet high by 5 feet 6 inches diameter. This is more economical in money and space than a single large stack. The switchboard is so arranged that any dynamo may be run alone or in parallel with others, with either its positive terminal to one 'bus bar, and its negative to ground, or with positive to ground and negative to another 'bus bar, while any feeder of the system may be connected to either 'bus bar. This corresponds to a 1,100 volt-system, and gives a smaller drop and greater freedom from electrolysis, due to the fact that large current does not return to the station through the ground, but distributes itself over a large area of the city, thus decreasing the necessary investment in ground wire. The disadvantages are complication of the switchboard and the necessity of having special 1,100 volt circuit-breakers on the lines, since failure of one of these breakers would produce a short circuit. A regulating storage battery is used. A novel feature is the interlocking pneumatic switchboard, somewhat similar to that at the Cataract Company's Station at Niagara Falls.

E. H. C.-H.

## *Cross-Country Line at Lewiston, U.S.A.*

(Electrical World, vol. xxxiii., 1899, pp. 255–258.)

The main line of the Lewiston, Brunswick, and Bath Street railway extends 30 miles from Lewiston to Bath, with urban branches at both ends, making a total of about 60 miles. Power for the whole line is obtained from falls near Brunswick, where 1,000 HP. has been leased for $10,000 per annum. Four Victor turbines, under 17 feet head, with Lombard governors, are all mounted on the same shaft, which drives the main countershaft by rope. Three 250 kilowatt double-current Westinghouse generators are driven by clutch-pulleys on the countershaft. The whole 250 kilowatts may be delivered through the commutator at one end of the armature, or taken as alternating current from collector rings at the other end, or in any proportion from both ends simultaneously. Speed is 600 revolutions per minute, frequency 60, direct current voltage 550, and three-phase voltage from the same windings 330. The machines are practically rotary converters, with an added pulley and outer bearing. They are compound-wound. The direct current panels of the switchboard are of the usual pattern; the three-phase generator-panels carry an ammeter on each phase, a triple-pole switch, and a special field resistance with field adjustment. The three-phase current is transformed in a separate building to 10,000 volts by Westinghouse, oil-insulated, self-cooling, 125 kilowatt transformers, with

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tappings so arranged that different numbers of turns can be cut off from one end of the low tension winding, thereby enabling the ratio of transformation to be changed by 6½ per cent., 12½ per cent., or 18¾ per cent. The 10,000 volt switches consist of plugs on the end of 3-foot wooden poles with flexible connections. The plugs enter brass sockets with spring contacts on marble slabs. The fuses consist of a foot of aluminium wire in soft rubber tube, supported on triple-petticoated porcelain insulators. Of the two high-tension lines one runs 10 miles and the other 20 miles, to rotary sub-stations. The converters are 10-pole machines at 720 revolutions per minute, with practically the same windings as the generators. They carry at one end small three-phase induction motors for starting the rotary, the motor being wound to give a high torque at standstill, and having a smaller number of poles than the rotary, so that it will bring the speed slightly above synchronism, giving a good opportunity for closing the main switch while passing the critical point.

E. H. C.-H.

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## *Stansstad-Engelberg Polyphase Railway.*

(Electrician, vol. xlii., 1899, pp. 460–465.)

The metre-gauge line is laid with 52-lb. Vignoles rails with steel sleepers. In parts a ladder rack is used, the first and last section of which are supported on strong conical springs, and have revolving teeth to prevent the pinions mounting. The bonded rails form the third wire of the three-phase system. Radial-flow high-pressure Pelton wheels are direct-coupled to three-phase generators with revolving armatures. With a head of 1,250 feet, the output of each set is 180 HP. The shunt-wound exciters are driven by 12 HP. turbines at 750 volts without governors. Three 30-kilowatt transformers behind the switchboard raise the voltage to 5,200. An automatic switch is arranged to interrupt the exciter current in case of an earth on the high-tension line. The two trolley wires of 7·5 millimetres diameter are suspended 3 feet apart on span wires. The high-tension line is carried on the outer side of the poles which also carry the low-tension feeder lines, fed from three single-phase transformers at a midway station. The State telephone line runs parallel to the railway, but buzzing is heard only on wet days. At one point the line crosses the main road by a drawbridge, and at another it crosses a direct-current tram line.

The 46-foot bogie motor cars weigh 14 tons empty, and carry forty-six passengers, with luggage and mails. The front bogie carries two 35-HP. 750-volt induction motors, running at 480 revolutions per minute and driving through single reduction gearing. Current is collected by two double sliding contacts. The stator current is controlled on the driver's platform by a two-way switch,

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under which are placed four enclosed high-tension fuses for the stator circuit of both motors. The third end of the stator winding is connected to the bogie frame. The rotor current is collected by double carbon brushes from the slip-rings, from whence it passes to the rotor resistance placed on the roof. The resistance is worked by a lever placed above the controller on the driver's platform. The cars are heated and lighted electrically, current for the lighting being supplied at 100 volts by a small transformer placed in the luggage compartment. The heaters are placed, seven in series, under the seats, and are connected directly to the 750-volt line. Each car is fitted with two brakes; the one is a powerful hand-brake applied to all the eight wheels of the car, the second is a pinion brake acting on the pinion placed on the rear bogie, and is only used when the car is running over the rack. The maximum speed for which the cars are designed is 12½ miles an hour; the speed is only varied by means of a rheostat in the rotor circuit.

The 12-ton locomotives carry two induction motors giving 75 HP. at 650 revolutions, and each weighing 2 tons. Both motors are geared to a common shaft, which is again geared to the driving pinion running in the rack. The gearing is so dimensioned as to give the locomotive a speed of 3·1 miles an hour on the rack. By means of a friction coupling and connecting-rod the motors can be connected to the driving wheel, making it possible to run the locomotive at a speed of 7½ miles an hour on the adhesion line. The rotors are controlled by a reversing switch in the stator circuit and a resistance in the rotor circuit. Three independent brakes are in use. The first is a hand-brake acting on the driving-wheels; the second is a hand-brake, acting by means of four gun-metal shoes pressed on two wheels keyed to the driving pinion; the third is an automatic brake, which acts as soon as the speed of the locomotive exceeds 4½ miles an hour on the rack. The latter consists in the main of a centrifugal governor keyed to the motor-shaft; this releases a weight, which in its fall opens the switch in the stator circuit and couples the brake spindle to the motor-shaft, so tightening the brake shoes on the brake pinion and on a pinion placed loose on the rear axle of the truck. By means of this brake it is possible to stop a train weighing 28½ tons, and going at a speed of 3 miles an hour, on the 25 per cent. gradient in a distance of 20 feet. The motor cars will draw a trailer up a 2·3 per cent. gradient at 12 miles per hour; while, on the rack, the locomotives push the car up at 3 miles per hour. In descending, the speed of the motors tends to rise above synchronism, and the current given back to the line then makes the turbines race, unless a car is going up or a water resistance is put into the generator circuit. Extensions to 600 HP. capacity are contemplated.[1] E. H. C.-H.

[1] Science Abstracts, 1899, No. 936.

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## *Lodge and Muirhead's Syntonic Coherer Telegraph.*

J. BLONDIN.

(L'Éclairage Électrique, vol. xviii., 1899, pp. 81–86.)

Other things being equal, a resonating receiver will respond to weaker waves, and therefore at greater distances than a non-syntonic one. The Righi spark-gap prevents the coil from seriously affecting the periodicity at the sending end and at the receiving end, as the receiver is normally a non-conductor. The Author thinks Lodge's precautions in connecting the resonator to it are of little use. Turpain's connections of 1895 are said to be almost identical with Lodge's. Tietz's experiments confirm the value of a condenser in the earth connection. Turpain studied in 1895, and published some months before Lodge, a system of Hertz waves transmission on telegraph networks.

M. O'G.

## *Candle-power of Glow-Lamps.* R. A. FESSENDEN.

(Electrical World, vol. xxxiii., 1899, p. 230.)

The Author measures the mean horizontal candle-power and divides it by the mean spherical candle-power; this ratio, expressed as a percentage, he calls the distribution factor. This varies from 72 to 84 in a number of experiments made. In general, the longer the filament of a given type of lamp the greater the distribution factor. In other words, a comparatively low resistance carbon should be used where uniform distribution is wished. Also, contrary to what was expected, there is practically little difference between horseshoe and looped filaments as met with in the market, so far as distribution is concerned, the average factor being 76 for looped filaments 8½ inches long, and 78 for horseshoe filaments 6 inches long.

E. C. R.

## *Ball Coherers.* E. BRANLY.

(Comptes Rendus, vol. cxxviii., 1899, pp. 1,089–1,092.)

After his experiments with metallic disks the Author has tried the effect of substituting for them a row of balls 1 centimetre in diameter. Since the large surface of the disks considerably reduces the density of the currents induced by the electric waves, it is to expected that balls are much more sensitive, and this is actually

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the case. Brass gives no result, and lead gives only very feeble indications of sensitiveness, but ten balls of soft iron mounted one above the other show an initial resistance of 990 ohms, which is reduced to 60 ohms by a spark of 1·5 millimetre passing at a distance of 10 metres. A slight shock sends it up to 1,300 ohms, and a second spark brings it down again to 80 ohms. Hard steel shows, under the same circumstances, the following succession of resistances: 600, 50, 2,060, 120, 2,520, 90. An important point is that a ball coherer consisting of six hard steel balls is just about as sensitive as a coherer of gold filings, which, as we know, is highly sensitive. But to obtain uniform effects the shock used for decohering must be carefully graduated. Slight repeated shocks produce conductivity. A stronger single shock produces resistance. A very hard knock brings about a nearly permanent resistance, which is not annulled by ordinary waves.

E. E. F.

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*Detecting Faults on Picking Up Submarine Cables.* E. JONA.

(Electrician, vol. xliii., 1899, pp. 15, 16.)

Currents are induced in the turns of cable which pass on to the picking-up drum. The galvanometer is connected between the picked-up end of the cable and the earth. The galvanometer throw shows a sudden alteration as soon as the fault passes over the drum. Details of a satisfactory trial at sea in 1898 are given.

M. O'G.

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*Detecting Faults on Picking Up Submarine Cables.*

W. J. MURPHY.

(Electrician, vol. xliii., 1899, pp. 12, 13.)

The variations of a high resistance fault which is being raised from the bottom increase the difficulties. An induction method similar to E. Jona's (see preceding Abstract) was tried in 1891. The use of high frequency, the earthing of the far end, the use of a telephone, a secohmeter, a Wehnelt interrupter and a condenser on the ship are suggested.

M. O'G.

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## *Electroplating the Hulls of Vessels.*

(Electrical Engineer, New York, vol. xxvii., 1899, pp. 131, 132.)

After a series of tests covering a period of 4 years a favourable report has been rendered to the United States Government on T. S. Crane's system of copper-plating the hulls of vessels. The ocean-going tug "Assistance" was electroplated and launched in February, 1895. A short time ago she was docked and subjected to a critical examination; her bottom was absolutely free from marine growth of any kind.

The method of electroplating consists primarily in the use of flexible shallow baths, open at one side, and being made water-tight by suitable flexible packing at the edges. The baths are made flexible in order to follow the curvature of the vessel, and are supported against its side or bottom by tension ropes, screw shores, or magnets. The vessel forms the negative pole, the plating bath the positive; the plating is done in sections which slightly overlap, so as to form a continuous coating. In order that the density of the solution may be kept uniform, circulation is effected by letting the solution flow into the bottom and out near the top of the bath. A current rate of $7\frac{1}{2}$ amperes per square foot and a potential difference of $1\frac{1}{2}$ volt give a uniform, smooth, and adherent coating to the metallic surface of the vessel.

The whole bottom of a ship 400 feet long, drawing 20 feet of water, can be plated in 8 days or 9 days, using about 55,500 lbs. of copper. The tests were conducted by the well-known electrical engineer A. A. Knudson and the electro-chemist W. J. Comly. The former says, in concluding his report, "I have discovered so far nothing about this boat that could be considered as a serious objection to this method of copper-plating the bottom of an iron or steel vessel, and I believe this invention will have a very important future. I suggest that not less than $\frac{1}{16}$ inch of copper-plating should be allowed."

It is claimed that as much as £4,000 per annum is expended by various ships in the trans-Atlantic trade to overcome the added friction caused by fouling, while the cost of docking a big ship twice a year would nearly double the total loss as a penalty for unprotected bottoms. An iron vessel with a speed of 20 knots, if coated with copper, will have, it is calculated, a speed of 21 knots.

A. S.

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## *Maxim's Method of Making Glow-Lamp Filaments.*

(Electrical Engineer, New York, vol. xxvii., 1899, pp. 174, 175; U.S. Patent, No. 618,704.)

In order to increase the resistance of incandescent lamp filaments for high-voltage lamps, H. S. Maxim mixes with the carbon of which the filaments are composed diamond dust, or a species of carbon closely resembling the diamond, and manufactured by the following process: In a cylindrical steel vessel, lined with a suitable refractory material and closed at each end by a screw plug bearing a carbon-pencil in a water-jacketed holder, there is placed carbonic acid in a liquid or solid (snow) form, together with carbon or a hydrocarbon such as gasolene. On heating the mixture by means of the voltaic arc, the $CO_2$ and the hydrocarbon are decomposed, CO being formed and a great pressure thereby generated in the vessel. By the continuance of such high pressure and temperature a very hard and crystalline form of carbon is produced, which, after its removal from the vessel, can be crushed into extremely fine powder. This powder is mixed with suitable vehicles, such as tar, pitch, or sugar, and then moulded with filaments, which are "retorted" and "flashed" in the usual manner.

C. K. F.

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## *Power from Blast Furnaces.* A. Witz.

(L'Éclairage Électrique, vol. xviii., 1899, pp. 401–407.)

Recent improvements in blast furnaces have resulted in a great increase in the production of pig-iron and a diminution of the fuel used. In America there are furnaces giving a daily output of 700 tons for an expenditure of $\frac{3}{4}$ ton of fuel per ton of pig-iron. Of the heat developed by the combustion of the fuel only about 29 per cent. is utilized in effecting the necessary chemical changes, and many attempts have been made to utilize the waste heat. In evaporating water in a steam-boiler about 22 cubic metres of blast-furnace gas are required per HP. hour. The Author has found that the calorific value of blast-furnace gas is, on the average, 1,000 calories per cubic metre, so the above consumption represents a thermodynamic efficiency of about 3 per cent. In other words, utilizing the waste heat to generate power by steam-engines and boilers, the best one may hope to obtain is about 450 I.HP. for a 100-ton furnace.

Gas-engines work with an expenditure of 2 cubic metres to 3 cubic metres of poor gas, and in 1894 Thwaite first made the attempt to utilize blast-furnace gas in a gas-engine. His first experiment at Wishaw, Scotland, was very satisfactory. The



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Author traces briefly the history of the utilization of the gas in this manner, gas-engines up to 600 HP. being used; while at Seraing there will soon be in operation a two-cylinder engine of 1,000 HP. The Author is of opinion that a combustion motor would be better than an explosion motor for the utilization of blast-furnace gases, but this is a type of engine that has yet to be created, and at present the only engines employed have been of the well-known explosion type. The power thus available is more than sufficient for all the operations required at an ironworks, and when the geographical conditions are favourable, the excess may be conveniently transmitted and distributed.[1]

A. S.

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## *Elevators for Central London Railway.*

(Engineering, vol. lxvii., 1899, pp. 273–276 and 306, 307.)

The lifts selected for the stations of the Central London Railway are made and designed by the Sprague Electric Company, New York. One of the conditions to be complied with was that, with an average total of 20,000 single trips per day of 67 feet mean rise, and with current at 1*d.* per Board of Trade unit, the elevators must be worked for 3 years at a cost not exceeding £1 per 1,000 trips. The diameters of the shafts in which the elevators work vary from 18 feet to 30 feet, three cars being placed in the larger shaft. Details of the construction and specification of the cars are given. The hoisting machinery is extremely simple and completely self-contained. Side frames mounted on a heavy cast-iron bed-plate carry bearings for the drum and idler shafts, and form oil-tanks, in which the worm-gear is enclosed. Directly coupled to the worm-shafts are the four-pole shunt-wound iron-clad motors, which, at 470 revolutions per minute, give a lift speed of 200 feet per minute. Each motor drives a shaft, on which are fixed right-handed and left-handed worms, gearing with two worm-wheels, lateral thrust on the drum-bearings being thus done away with, and the thrust of one worm being balanced by that of the other. As a safety device the usual Sprague jaw-clamps are used, specially modified for the conditions. Each safety-catch is calculated on the basis of a loaded car weighing 40,000 lbs., having to be supported by friction only between the clamps and the guide-rails, the assumed frictional coefficient being 15 per cent. As an additional safeguard oil-buffers are placed on all cars and counter-weights. These are large dashpots with plungers, having tapering grooves on their external surfaces, which allow the cars to settle rapidly when the buffer first comes into operation, the settlement becoming slower as the grooves narrow.

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[1] Science Abstracts, 1898, Nos. 991, 992, and 993.

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The experimental lift erected at Notting Hill Gate under the conditions of the contract has been subjected to rigorous tests with most satisfactory results.

A. S.

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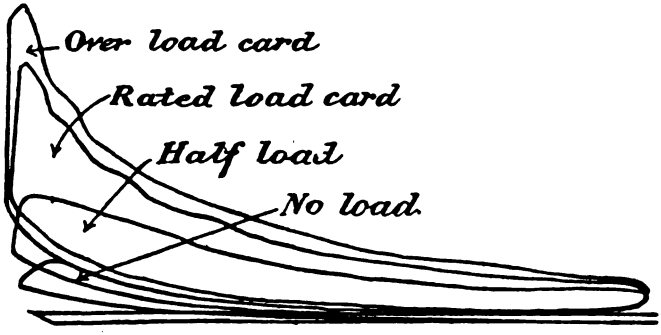
*Recent Developments in Gas-Engines.* E. RUUD.

(Electrical Engineer, New York, vol. xxvii., 1899, pp. 255–257.)

Large gas-engines work on the "Otto" or "Beau de Rochas" cycle, and fall into two classes, depending on the mode of regulating the speed:—

(1) In the "hit and miss" governing type chiefly in use one or more charges of gas are cut out altogether. Where uniform speed is required, as in electric lighting, the "hit and miss" gas-engine must have heavy fly-wheels, and a heavy balance-wheel is usually mounted on the jack shaft. The variation in voltage on a 100-volt circuit is generally from 3½ volts to 4 volts during the cycle. When the engine takes in a few charges successively the voltage is steady and rising, but when the engine omits one or more charges a momentary variation in speed is the result, and




fluctuation is apparent in the lights. The loss of power by the two belts is about 7 per cent., and by the jack shaft 3 per cent., making a total of 10 per cent. taken by the extra machinery. One advantageous feature of this type of gas-engine is that the charge is always ignited under the same pressure, and hence the actual work done by the exploding gases in a cycle is practically the same for full load as for no load.

(2) In another type of gas-engine adapted for electric lighting the speed regulation is said to be as good as that of a first-class steam-engine. The armature is on the crank-shaft, direct-coupled or directly belted. The mode of governing is similar to that of the steam-engine. All charges are proportioned to the load. If

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the entire load is suddenly thrown off at once, which seldom occurs, there is one heavy charge already in the engine, although the governor acts instantly, and there may be another under way partially reduced by the action of the governor. This tends to speed up the engine slightly above the normal, but it is reduced by the fly-wheels. The indicator diagrams give an idea of the governing action of a Westinghouse gas-engine of this type.

The gas-consumption in all engines varies with the kind of gas used, and also with the size of engine up to certain limits. The average in the Westinghouse gas-engine, from 20 HP. upwards at everyday work, is 10·5 cubic feet to 12 cubic feet of Pittsburg natural gas per B.HP. hour. The heating value of natural gas, found by the Junker calorimeter, is about 1,000 B.T.U. per cubic foot; that is, the engine requires 10,500 B.T.U. to 12,000 B.T.U. for each B.HP. hour, giving a thermal efficiency at the shaft of 25·4 per cent. and 21·3 per cent. A special engine of 125 B.HP. used only 9 cubic feet per B.HP. hour, or had a thermal efficiency of 28·7 per cent.

The consumption of water flowing through the cylinder jackets is about 30 lbs., and in summer 38 lbs. to 40 lbs. per B.HP. hour. Where water is expensive, it may be used over and over again in cooling tanks or by pumping the water to a cooling-tower, and the loss of water need only be a few gallons per week. In some tests it was found that 5,121 thermal units went out in the cooling water, 2,922 thermal units were converted into work, so that 2,957 thermal units must be lost by the exhaust and radiation.

In the spring, 1898, an engine of 650 B.HP. was completed in the works of the Westinghouse Machine Company. This engine has three vertical cylinders, and speed of 150 revolutions per minute. Another three-cylinder gas-engine is in hand, designed to give 1,500 B.HP. at 100 revolutions per minute on 8½ cubic feet of natural gas per B.HP. hour, or 8,500 B.T.U per B.HP. hour, that is, a thermal efficiency of 30 per cent. at the shaft. Such an engine will run every day on less than 1 lb. of coal burned in a producer-gas plant per B.HP. hour, including banking of fires and similar losses.

W. R.

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## 150-*Ton Electric Jib Crane.* W. A. Post.

(Electrical Engineer, New York, vol. xxvii., 1899, pp. 134–137.)

Early in 1896 the Newport News Shipbuilding and Dry Dock Company resolved to provide a crane capable of lifting the heaviest single weight likely to be met with in the probable development of modern ships. Careful consideration of all the requirements led to the adoption of a 150-ton revolving crane electrically operated,

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mounted on a steel tower on pile foundations. The jib is capable of having its outer end raised or lowered, so that the derrick may operate on weights lying within two concentric circles of 207 feet and 88 feet diameters respectively. The feature of varying the radius at which the hoisting may be performed constitutes a most important difference between the crane and the 130-ton steam-crane erected in 1893 at Finneston Quay, Glasgow.

The foundations consist of 150 piles in four concentric rows. The steel tower is, in general form, a cylinder 36 feet diameter, and is comprised of sixteen columns braced and anchored to the pile foundations below. A description of the revolving structure is given. The derrick is revolved by duplicate sets of machinery, each motor being of 20 HP., and working through a double-threaded worm and wheel, which drives a pinion engaging on a circular rack on the outside of the tower. The racking movement of the jib is effected by two 1¼-inch steel-wire ropes, each rope being wound on alternate sheaves 5-foot pitch diameter on 10-inch steel pins at the upper and inner apex of the jib and at the upper apex of the housing. Each rope is strong enough to sustain the jib when under maximum load. There are two main hoists, each of 75 tons capacity, and one of 20 tons capacity for lighter loads. The drums are 8½ feet diameter, and are driven through a train of gearing by a 100-HP. electric motor, series wound. These hoists may be coupled together and operated as one hoist of 150 tons capacity. The brakes are powerful, certain, and automatic in action. The brake band is wound four and a half times round a brake cylinder on the pinion shaft, and is of wrought iron 1 inch thick, 5 inches wide at one end, and tapering to 1¼ inch at the other. The broad end is firmly anchored, the narrow one secured to a lever carrying a weight of 200 lbs. When lowering, the rotation of the brake cylinders is towards the small end of the band, so that the friction produced by the weight causes the band to wind tight on the cylinder and stop rotation. To release the brake it is only necessary to lift the weight, which is done by means of a wire connected to a lever in the operating-house. In hoisting the brake releases itself.

A. S.

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## *Subdivision of Dynamo E.M.F. and Excitation of Half P.D.*

A. SENGEL.

(L'Éclairage Électrique, vol. xviii., 1899, pp. 188–193; also Elektrotechnische Zeitschrift, vol xix., 1898, p. 544.)

The first part of the Paper deals with the various methods of subdividing the electromotive force of a dynamo so that, *e.g.*, a single machine may be used for supplying a three-wire network. In the methods described, which are illustrated in the accompanying

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diagrams, *Figs. 1–4*, one or more points in the armature winding are connected to slip-rings, and by a suitable arrangement of choking coils interposed between the balancing wire and the slip-rings satisfactory working may be secured. *Fig. 1* is not to be recommended, as the arrangement is not entirely free from fluctuations in the potential of the balancing wire. *Fig. 2* and *Fig. 3* give satisfactory results. *Fig. 4* represents a device due to Ettingshausen; between the slip-ring and two diametrically opposite points in the winding are interposed two auxiliary

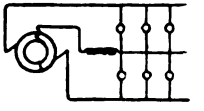
FIG. 1

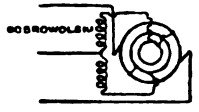

FIG 2

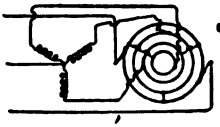
FIG. 3

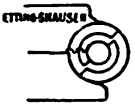

FIG 4

FIG 5

windings, each covering half the core, and each containing a number of conductors equal to half that in the corresponding main winding.

The second part of the Paper is concerned with the methods of shunt-excitation at half the terminal potential difference. The arrangement proposed by the Author for a short-wound motor is sketched in *Fig. 5*. The advantage of such a device lies in the fact that a wire of double the sectional area may be used for winding the shunt, so that the cost of the field winding is considerably reduced.

A. H.

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## *Armature Design.* C. WESTPHAL.

(Elektrotechnische Zeitschrift, vol. xx., 1899, p. 118.)

The Author deduces the two following formulas for the interconnection of the armature conductors in multipolar dynamos :—

$$y = \frac{1}{p}\left(\frac{s}{c} \cdot b \pm a\right) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$y_1 + y_2 = \frac{1}{p}\left(\frac{s}{c} \cdot b \pm 2a\right) \quad . \quad . \quad . \quad . \quad (2)$$

where $2p$ = the number of poles; $s$ = the number of inducing bars

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or conductors around the armature; $c$ = the number of these bars in each section; $b$ = a whole number; $2a$ = the number of circuits in parallel with each other. In formula (1), which relates to the case where the beginning and end of each element lie on one and the same end face of the armature, $y$ = the "pitch," or number of bars which lie between the commencements of two successive elements in the winding. In formula (2), which relates to the case where the beginning and end of an element lie on different ends of the armature, $y_1 + y_2$ = the double pitch. Reference is made to the work of E. Arnold on *Ankerwickelungen*.

C. K. F.

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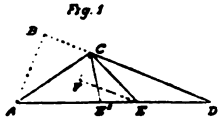
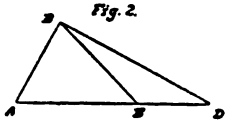
## *Transforming Single-Phase to Polyphase Currents.*

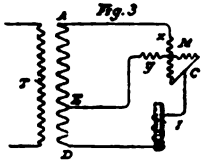
(Electrical Engineer, New York, vol. xxvii., 1899, p. 133.)

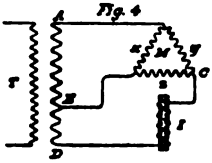
A method of deriving two or more alternating currents differing from one another in phase from a source supplying single-phase currents has been devised by H. A. Wagner, of St. Louis. The accompanying figures show how this is accomplished.

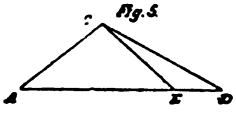
In *Fig. 1* A D represents in magnitude and direction the electro-




motive force of a source, such as the secondary of a transformer, C D the electromotive force across the terminals of an inductance coil, forming a derived circuit differing in phase from the electromotive force A D by the angle A D C, and A C the resultant electromotive force across the terminals of a working circuit

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derived from the source A D and made to differ from it by the angle C A D through the effect of the inductance C D.

If another circuit is connected from the point C to some point E on A D, an angle A C E is formed with the circuit A C. This angle represents the difference of phase between the derived circuits A C and C E. The point E may be moved in either direction along A D to any other position as $E^1$, and the phase relation of C E, as well as its relative electromotive, be altered as desired. If there is no self-induction in the circuit A C, it will assume the position A B at right angles to B D, and the relative phase angles and magnitudes then acquired by the different circuits are shown in *Fig. 2*. The flow of a comparatively large amount of current in a derived circuit such as C E will cause a slight decrease in the angle C A D by the nearer approach of C to D. This can be corrected by increasing the inductance C D, or the phase relations between A C and A E can be retained by moving the point of connection E.

*Fig. 3* shows the application of the principle to the operation of a two-phase motor. T is a transformer with secondary coil A D. M is a motor with its two sets of coils, *x* and *y*, joined at C and with their other terminals connected, one to A and the other to E, and I an inductance between C and D.

*Fig. 4* represents a three-phase motor M with sets of coils, *x*, *y*, and *z*.

*Fig. 5* shows graphically the phase angles obtained in the arrangement given by *Fig. 4*.

W. G. R.

## *Working Expenses of Electric and Cable Railways.*

(Railway World, vol. viii., 1899, pp. 132, 133.)

Details are given of the expenses, receipts, &c., of the only three lines in England the accounts of which are available. The totals for the last half of 1898 were as follows :—

LIVERPOOL OVERHEAD ELECTRIC RAILWAY.

| Expenses per train-mile. | Receipts per train-mile. | Percentage of expenses to receipts. | Miles run. | Passengers carried. |
|---|---|---|---|---|
| 14·92 | 26·12 | 57·12 | 373,560 | 4,894,921 |
| CITY AND SOUTH LONDON ELECTRIC RAILWAY. | | | | |
| 15·88 | 28·28 | 56·15 | 234,166 | 3,462,814 |
| GLASGOW DISTRICT CABLE SUBWAY. | | | | |
| 7·13 | 15·54 | 45·38 | 554,770 | 6,666,082 |

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To facilitate comparison of these results, the following data are given:—

| — | Liverpool Overhead. | City and South London. | Glasgow Subway. |
|---|---|---|---|
| Number of cars in train . . . | 2 | 3 | 2 |
| Passenger accommodation (seated) | 114 | 96 | 66 |
| Weight of train, empty . . . | 31 tons | 31 tons | 13½ tons |
| Weight of train, all seats occupied | 38 tons | 37 tons | 18 tons |
| Receipts per passenger carried . | 2*d.* | 1½*d.* | 1½*d.* |
| Length of railway (double track) | 6¾ miles | 3 miles | 6¾ miles |
| Train-miles run per double-track mile . . . . . | 55,342 | 78,055 | 82,151 |

From the Glasgow statistics, where single-gripper cars were used in the early part of the year, and trail cars in the second half-year, it appears that an increase of 50 per cent. in the dead load of cars made no increase in total working expenses, showing the merit of cable haulage for heavy work.

E. H. C.-H.

*Electric Brakes as Recuperating Devices.* F. B. Booth.

(Electrical World and Electrical Engineer, New York, vol. xxxiii., 1899, pp. 435, 436.)

The objection to combining the functions of electric braking and recuperation of the cells is that all the retarding force of the brake has to be transmitted through gearing which is liable to be stripped. The best form of electric brake is a mechanical shoe applied by an electromagnet energised by the motor running as a dynamo or by current from the battery when the speed decreases. It is impracticable to use the charging combination as an emergency brake; it should only be used on steep hills, and its retarding qualities should be regarded as incidental. Consider a vehicle of 2,000 lbs. with pneumatic tyres; this would require 50 lbs. draw-bar pull on good level roads at moderate speeds. On descending a 5 per cent. grade, gravity exerts a pull of 100 lbs., or 50 lbs. in excess of the pull necessary to maintain the assumed speed of 5 miles per hour downhill. Assuming an overall efficiency of 66·5 per cent., the power returned to the batteries will be only 243 foot-lbs. per second, whereas to ascend the same grade requires 1,447 foot-lbs. per second. The energy returned will only propel the vehicle for a level distance equal to half the length of the hill descended. Curves are given showing the maximum percentage of return on different grades, proving that a recuperating device is valueless unless grades of more than 6 per cent. are frequently encountered.

E. H. C.-H.

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## *Use of Magnets instead of Springs in Trolley Bases.*

A. HECKER.

(Zeitschr. Elektrotechn., vol. v., 1899, pp. 38–40.)

The trolley pole must be allowed considerable up-and-down play in cases where the height of the overhead conductor above the rails is very variable. It then not unfrequently happens that on the trolley leaving the conductor the pole strikes and breaks a number of span-wires before the car comes to rest. In order to avoid this risk, the Author proposes to dispense entirely with springs in the trolley base, and to substitute for them a coil-and-plunger mechanism traversed by the main current. If the trolley should be thrown off the conductor, the excitation of the magnet ceases, and the trolley pole falls down by gravity out of harm's way. Illustrations are given showing details of the proposed arrangement.

A. H.

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## *Rail Bonding.*

(Zeitschr. Elektrotechn., vol. iv., 1899, pp. 32, 33.)

The method consists in using a supplementary copper conductor which follows the line of the track and is bonded to each length of rail. The bond itself consists of a thimble and short flat pin which fits inside it. The thimble and pin are both perforated with circular holes lying along a diameter of the thimble (*i.e.*, at right angles to its axis). The copper conductor is passed through these holes, the thimble is inserted into a hole in the web of the rail, and the flat pin driven in with a blow from a sledge-hammer. The copper conductor—which must be of very soft copper—is thereby bent into the shape of a ∪, the two limbs of the ∪ fitting into corresponding circular channels (one on each side of the flat pin) in the thimble. The latter is expanded and forced tightly against the sides of the hole in the rail.

A. H.

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## *A 95-Volt Arc-Lamp.* A. D. ADAMS.

(Electrical Engineer, New York, vol. xxvii., 1899, p. 222.)

In a form of enclosed arc-lamp working on 110-volt mains at the Boylston Café, Boston, Mass., U.S.A., the regulating coils are shunted by an induction coil. This causes every change in pressure and current at the arc to be opposed by the inductive action of the coil. Thus a much larger percentage of the line

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pressure is available at the arc, which in this lamp burns regularly at 95 volts. Comparative tests of this lamp and an enclosed arc-lamp working with 78 volts at the arc gave the following results:—

| | Long Arc. | Short Arc. |
|---|---|---|
| Volts at main | 110·00 | 110·00 |
| Volts at arc | 95·30 | 78·10 |
| Amperes | 4·19 | 4·12 |
| Watts to lamp | 461·00 | 452·00 |
| Watts to arc | 398·00 | 322·00 |
| Mean spherical candle power | 128·00 | 91·30 |
| Watts per spherical candle-power lamp | 3·59 | 4·96 |
| Watts per spherical candle-power arc | 3·11 | 3·50 |
| Gain in efficiency in lamp | 27 per cent. | |
| Gain in efficiency in arc | 11 per cent. | |

One spherical candle power cost 27 per cent. less from the mains.
One watt taken by lamp will give 35 per cent. more light.

C. K. F.

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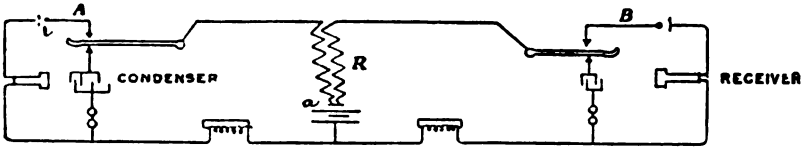
## *Centralized Sources of Energy in Telephone Exchanges.*

K. B. MILLER.

(Electrical World, vol. xxxiii., 1899, pp. 178, 179.)

The system of H. V. Hayes of the American Bell Company in 1892, which is rapidly spreading, is described.

It will be seen from the figure that fluctuations in the transmitter B affect the coil R and act inductively on the circuit of transmitter




A. Stone's method, involving a secondary cell at each subscriber station, is described. H. M. Crane's cord circuit relay is described and the credit of the development of these methods ascribed to the engineers of the Bell and Western Electric Company.

M. O'G.

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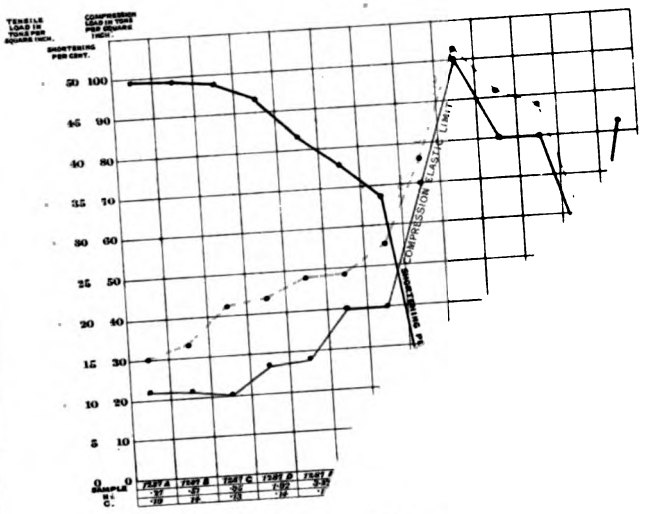


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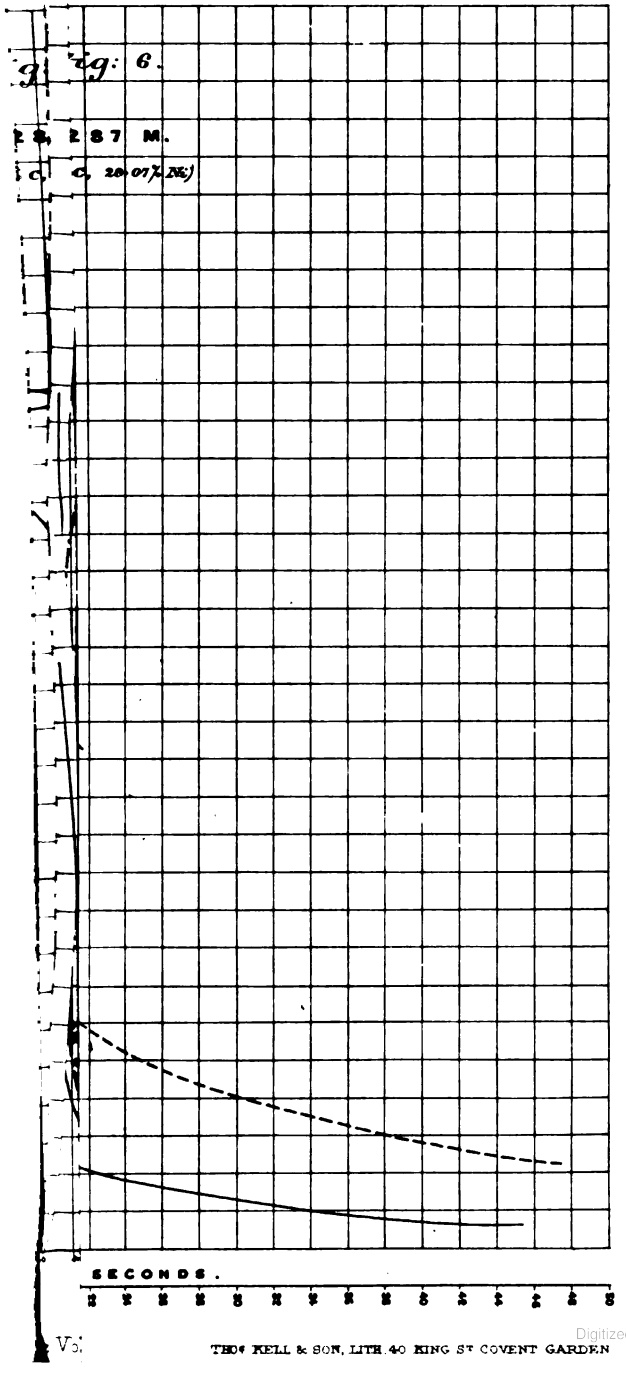


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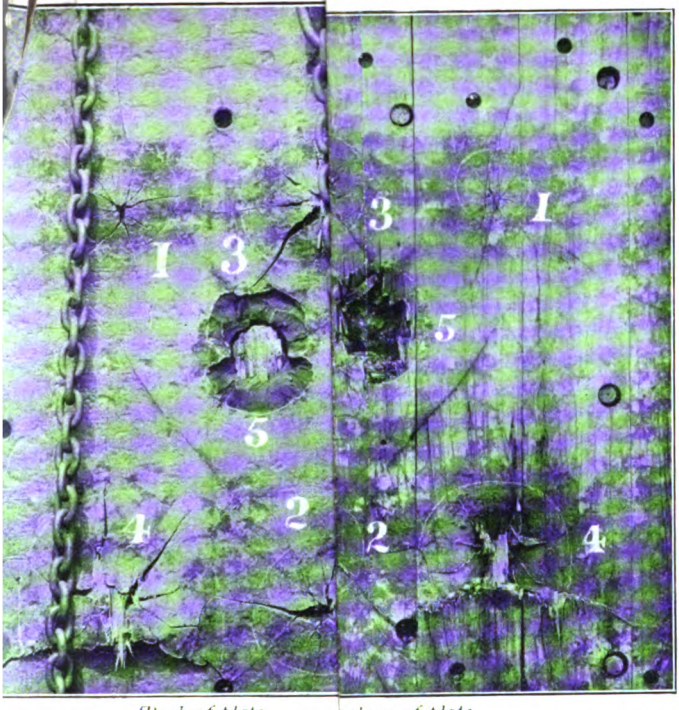


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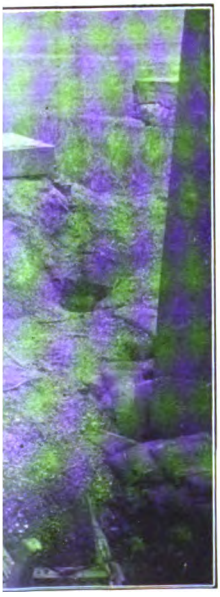

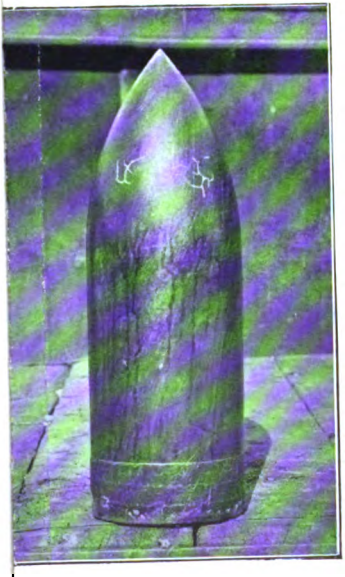

EL-STEEL PROJECTILE PLATE.

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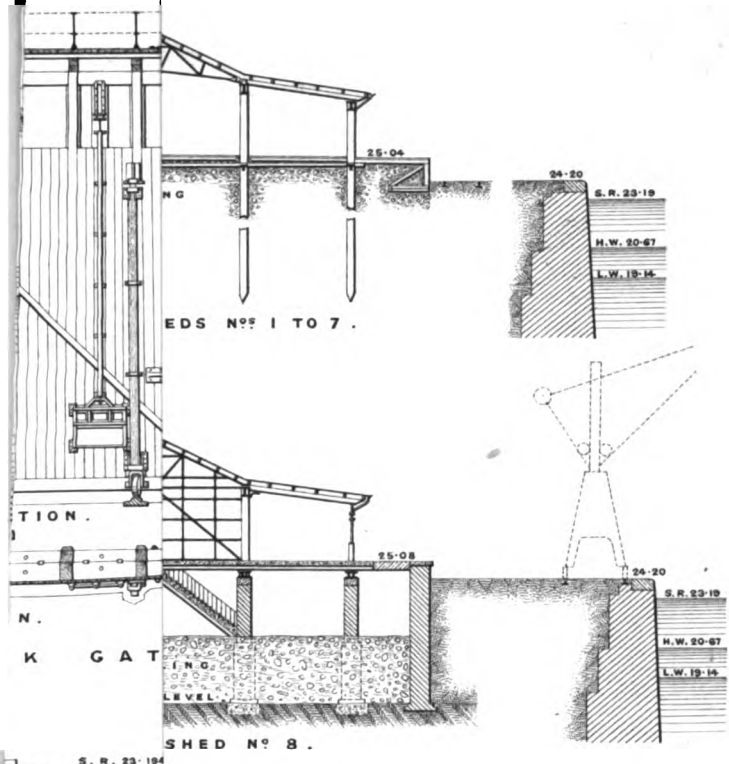
PLATE 4.

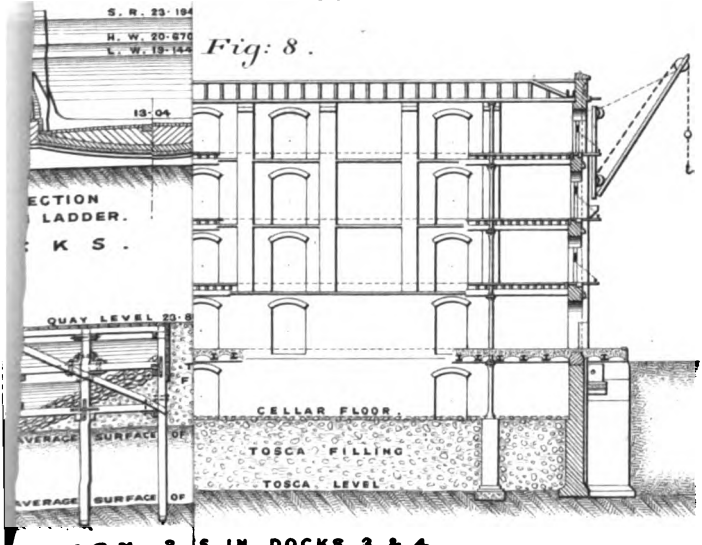
*Figs 7.*




EDS Nos 1 TO 7.

SHED No 8.

*Fig: 8.*

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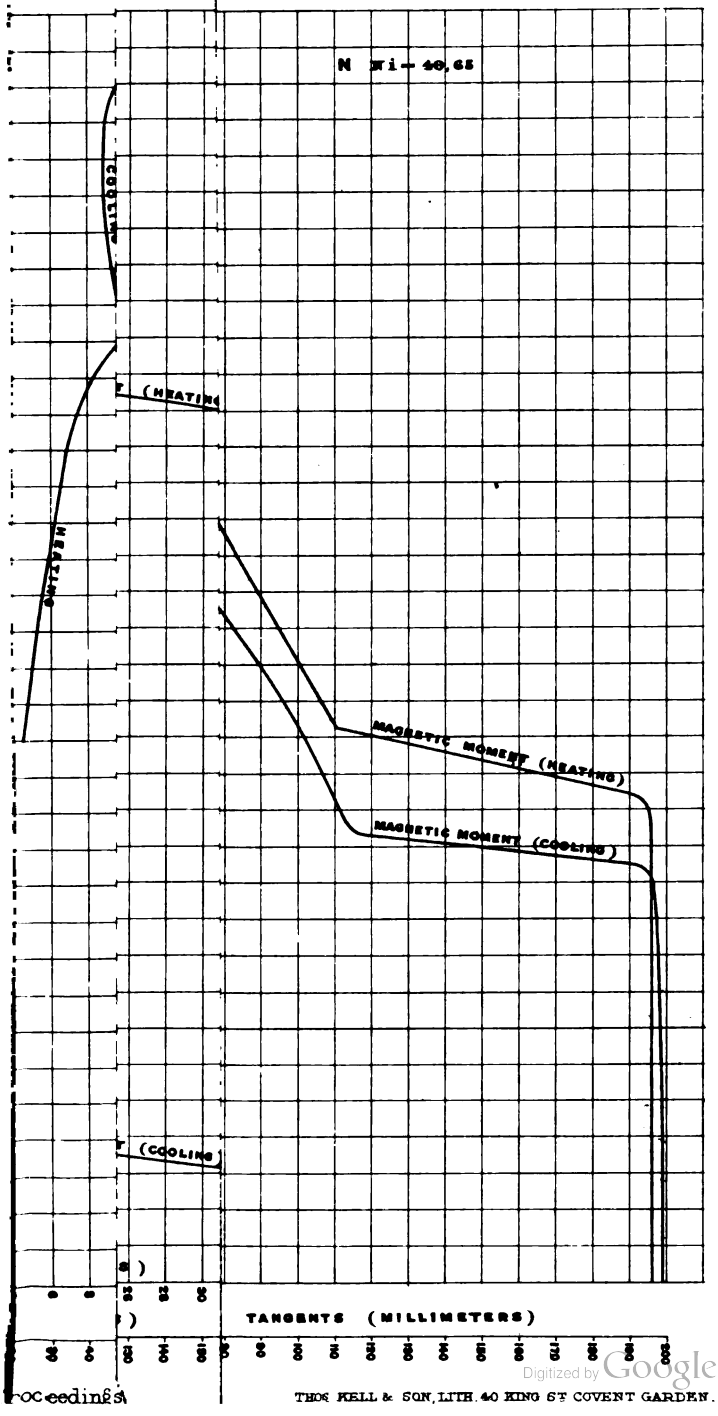


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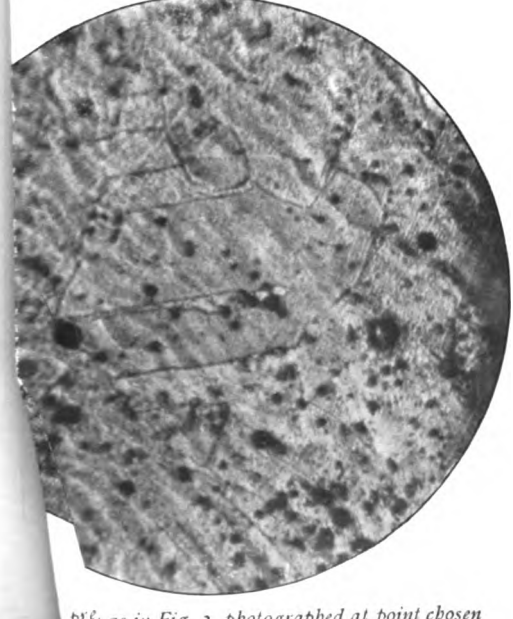
Fig. B.

*ning 58·3% Ni, annealed from 1300°C, treated with 10% H Cl. for 15 secs. at positive pole of bichromate cell*

Fig. D.



*pre as in Fig. 3, photographed at point chosen o show laminar structure.*

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*Fig: 5.*

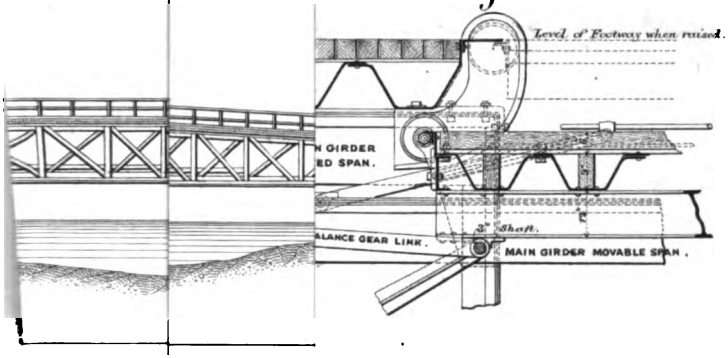



*Fig: 6.*

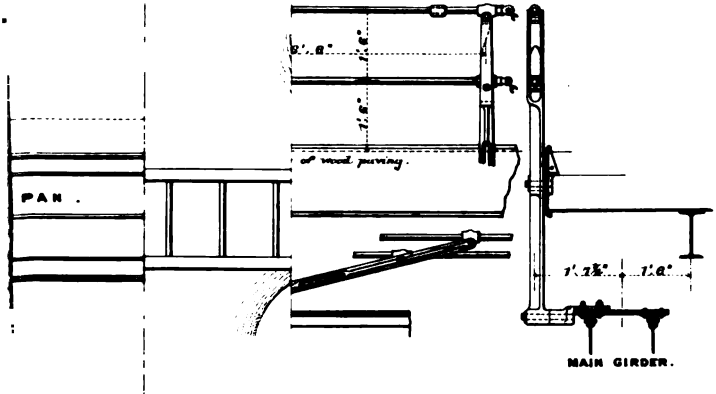
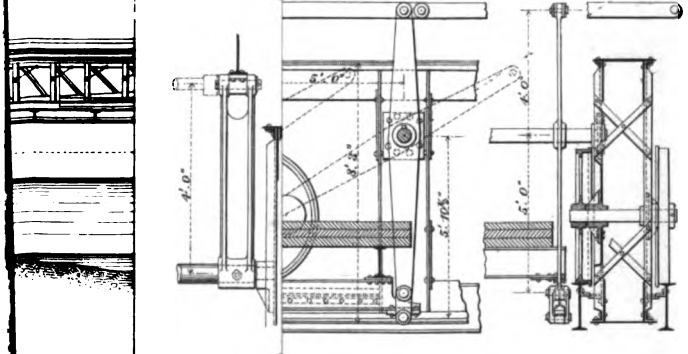



*Fig: 4.*



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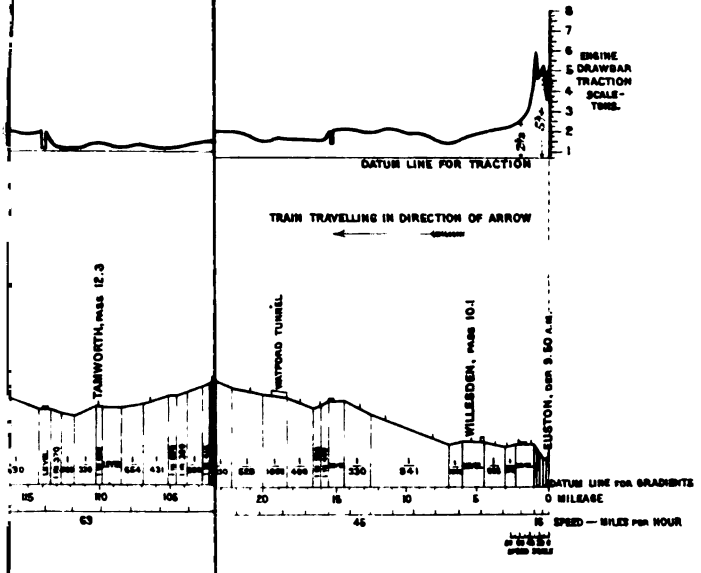
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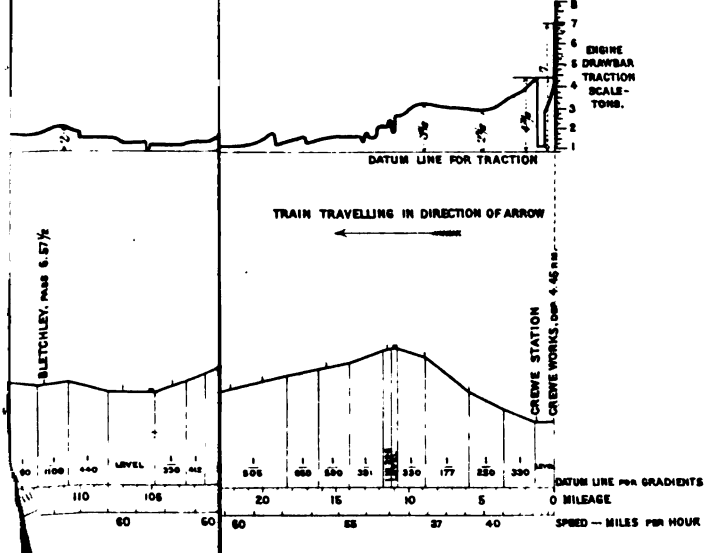
DATUM LINE FOR TRACTION
TRAIN TRAVELLING IN DIRECTION OF ARROW
TAMWORTH, PASS 12.3
WILLESDEN, PASS 10.1
EUSTON, DEP 9.50 A.M.
DATUM LINE FOR GRADIENTS
MILEAGE
SPEED — MILES PER HOUR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DATUM LINE FOR TRACTION
TRAIN TRAVELLING IN DIRECTION OF ARROW
BLETCHLEY, PASS 6.57½
CREWE STATION
CREWE WORKS, DEP 4.45 P.M.
DATUM LINE FOR GRADIENTS
MILEAGE
SPEED — MILES PER HOUR

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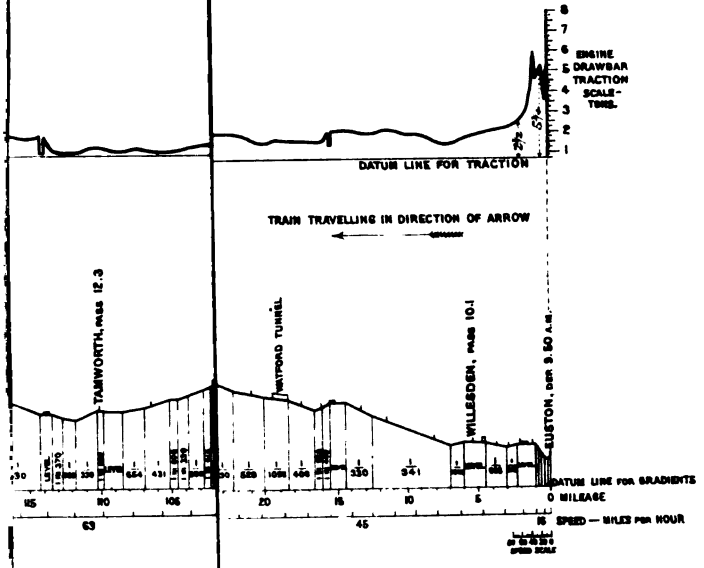


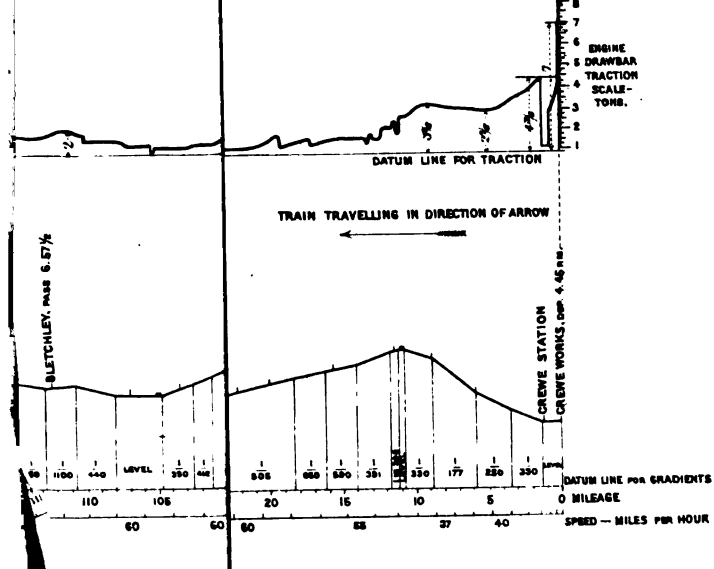


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# SUBJECT-INDEX.

VOLS. CXIX. TO CXXXVIII. SESSIONS 1894–95 TO 1898–99.

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MINUTES OF PROCEEDINGS

OF

# THE INSTITUTION OF CIVIL ENGINEERS.

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